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Contract No. Cac-47-5
Industrial and Research Development Division
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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of Democracy, and while guided and controlled by virtue, the noblest attribute of man. It is the only dictator that freemen acknowledge, and the only security which freemen desire.

Mirabeau B. Lamar

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Preface

Precast tile and reinforced concrete floor systems have been used extensively in Iowa and the Southwest during the past ten years. The low cost of these floor systems, coupled with their fire resistance, makes them highly desirable for use in residential, school, and light commercial structures. However, there have been a number of unknowns about the structural properties of the composite beams of tile and reinforced concrete.

1. Is the bond between the tile and concrete sufficient to allow the composite beam to act as a unit?
2. What is the effect of the tile shells on the diagonal tensile strength of the beams?
3. What is the effect of the quality of tile on the diagonal tensile strength of the beams?
4. How do the tile-concrete beams compare with the ordinary reinforced concrete beams?
5. What should be the design procedure for this type of construction?

This is a report of an investigation of the joistile type of construction started for the purpose of determining the answers to these questions. It has been made possible by the Industrial and Research Development Division of the Office of Technical Services in the U. S. Department of Commerce, Washington 25, D. C., under the provisions of Contract No. Cac-47-5 with The University of Texas.

The writers of this report wish to express their gratitude to Professor Phil M. Ferguson of the Civil Engineering Department, The University of Texas; Mr. Harry Plummer, Director of Research of the Clay Products Institute, Mr. W. G. Demarest, Manager of the Clay Products Association of the Southwest, and Mr. Douglas E. Parsons, U. S. Bureau of Standards, for their very helpful suggestions in the performance of the work and preparation of this report.

J. NEILS THOMPSON
Director

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Introduction

The first reinforced masonry structure was the Thames tunnel. This tunnel was designed and constructed by Sir Marc Isambard Brunel between 1830 and 1835. The shaft was 50 feet in diameter and 42 feet in height with 48 wrought iron bolts of one inch diameter attached to wood curbs at the bottom and top. The shaft was constructed and then lowered by excavating the gravel from the interior. At one time on lowering its strength was severely tested, but it did not fail, when one side struck soft earth and caused a differential settlement of 3½ inches.

In 1836 Brunel built the "Nine Elms Beam." It was an inverted T-section, 57 inches deep, 24 inches wide for the lower and 18 inches and 19 inches wide for the upper part. It had a clear span of 21 feet and had seventeen 1¼ x 1/16 inch iron bands for reinforcing. It stood for two years with a load of 24,000 pounds and then was tested to destruction under 68,300 pounds.

In 1851 at the London Building Exhibition, a beam similar to the "Nine Elms Beam" was tested as one of the first demonstrations of Portland Cement. It carried about five times the load carried by the "Nine Elms Beam."

In 1922, Mr. A. Brebner, Undersecretary, Government of India, Public Works Department, in a paper, "Notes on Reinforced Brickwork," reported that due to the high cost of form timber for concrete, there is a rather wide use of reinforced brick in India. The report included tests conducted on slabs, beams, cantilevers, etc., with similar tests on reinforced concrete. He concluded that reinforced concrete design theory would apply to reinforced brick masonry. Subsequent tests by several investigators have established that the design procedure used for reinforced concrete design could be used for reinforced tile units.

In 1938, there was developed in Iowa a tile unit known as the "T-Beam" tile which was solely for making precast composite tile-concrete beams. This tile is shown in Figure 1. The purpose of it is to permit the formation of precast beams which, when placed with the proper spanner tile, form a support on which a concrete topping may be poured. When completed, this type of construction results in a composite floor system made of the tile-concrete beams and the concrete topping. The bond between the tile and the concrete is sufficient to cause the two materials to act as a unit. In 1941, Henry Giese and Charles T. Bridgman reported in Research Bulletin 286, of the Agricultural Experiment Station of Iowa State College of Agriculture and Mechanic Arts the results of a series of tests performed on this type of beams and floor slabs. The results of their tests revealed that it would be safe to design the composite tile-concrete beams using the same design procedure as is recommended by the American Concrete Institute Building Code or the Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete.

It has been accepted rather broadly that the design methods used for reinforced concrete were suitable for stresses due to moment and bending, but some engineers questioned the use of this procedure in designing for shear and diagonal tension stresses. As a result a series of tests on Economy "U" tile were performed and reported by J. Neils Thompson

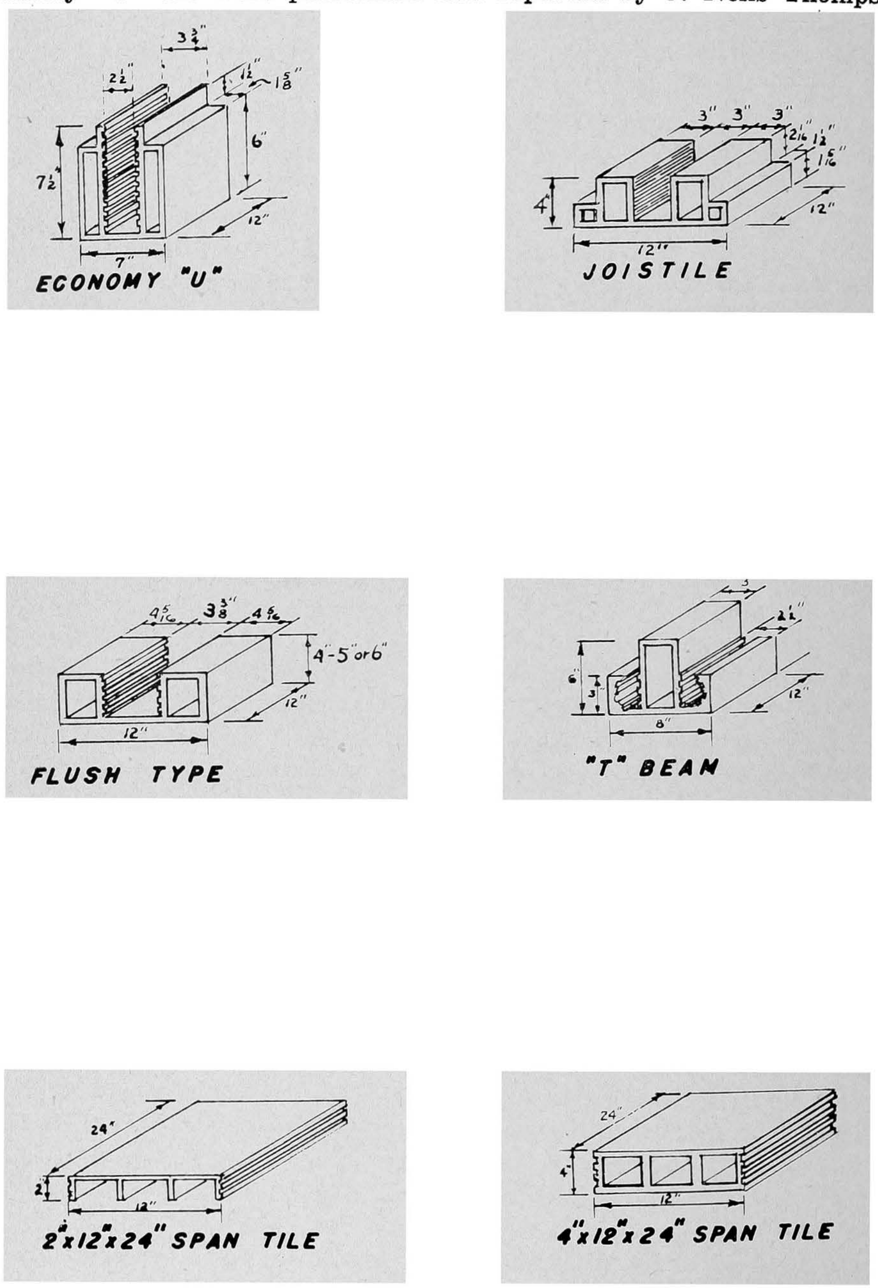


Figure 1

and W. D. Ramey in Bulletin No. 41 of the Bureau of Engineering Research of The University of Texas, January, 1947. It was found from these tests that the diagonal tension or shear strength of tile-concrete beams was higher than equivalent concrete beams. This was attributed to the greater tensile strength of the tile.

Since the development of the "T-Beam" tile, there has been a continued development of tile for the purpose of building precast tile-concrete floor systems. Some of the different types of tile developed are shown in Figure 1. The joistile has been developed recently and it seems to be

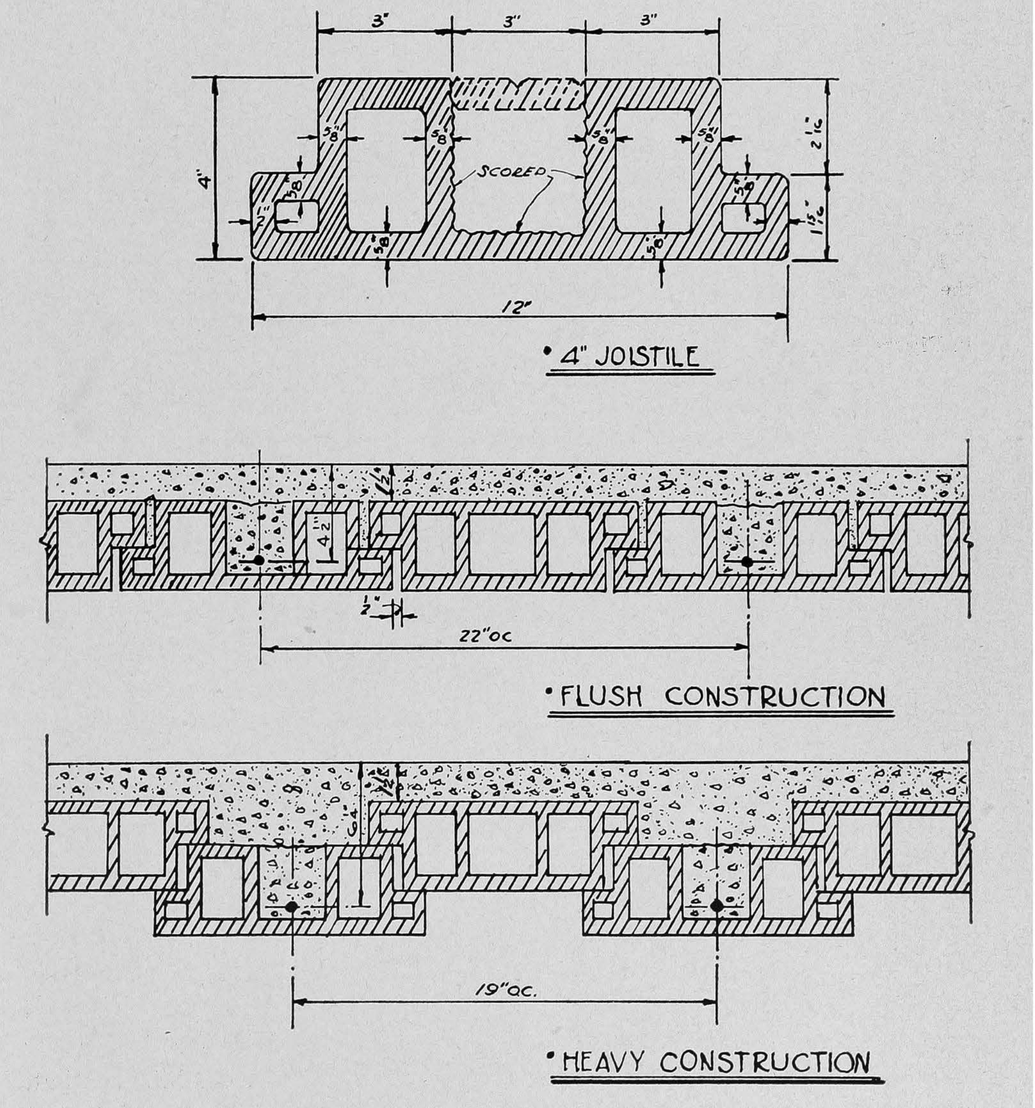


Figure 2

one of the most practical. There are several features about the joistile which make it more desirable than the other tile. These are: (1) the spanner tile and the beam tile are of the same design, cutting down on production cost, (2) there is less loss due to handling than there is in the spanner tile of the other types, and (3) the arrangements of the tile as shown in Figure 2 will allow two different depths of beams.

A floor or roof slab of joistile beams is built in five steps:

1. The "knock-out piece," on the joistile detail in Figure 2, is broken out by tapping sharply at the center. The joistile are then laid in line, end to end, on a firm flat surface until the desired length of beam is obtained. This forms a trough running the length of the row of tile as shown in Figures 3 and 4.

2. After placing reinforcing steel in the trough, it is filled with concrete or mortar. As soon as the concrete has cured, the tile-concrete beam can be handled as shown in Figure 5.

3. The joistile beams are then placed on their supports, either bearing walls or girders, and properly spaced for the design to be used. Unless the beams are very short (under ten feet), they will deflect excessively and this is corrected by shoring them at the center as shown in Figure 7.

4. Filler tile, of the same design as the joistile, but without the scoring that forms the "knock-out piece," are then dropped between the beams. At this point, although the slab is not complete, its strength is ample to carry the construction load as shown in Figure 6.

5. For the final step, top reinforcing is put in place if the design calls for it, piping and electrical conduits are set and the whole surface is covered with a topping of concrete of a depth determined in the design. The topping is kept damp during curing and when it has attained the required strength, the shoring is then removed and the resulting slab is a solid, fireproof and permanent construction.

From research work and the use of this or similar types of construction in the past, this composite floor system has been approved by building codes and specifications under certain restrictions. However, some engineers believe that these restrictions can be reduced. The work reported herein has been done in an effort to clarify and improve the design procedure for this type of construction. In the interest of encouraging the development of low cost type of construction the Industrial Research and Development Division of the Office of Technical Services, Department of Commerce provided funds for The University of Texas to carry on these investigations.

This investigation includes studies of: (1) A comparison of diagonal tensile strength of the tile-concrete beams with concrete beams, (2) the effect of the strength of tile on the diagonal tensile strength of the tile-concrete beams, (3) the adequacy of the bond between the beam tile and the concrete, (4) the proper cross section to be used in the design for diagonal tension resistance. Previous research work has established that, for bending stresses in the tile-concrete beams, ordinary reinforced concrete T-beam design should be used.

FIG. 3. Joistile being laid in line for precasting.

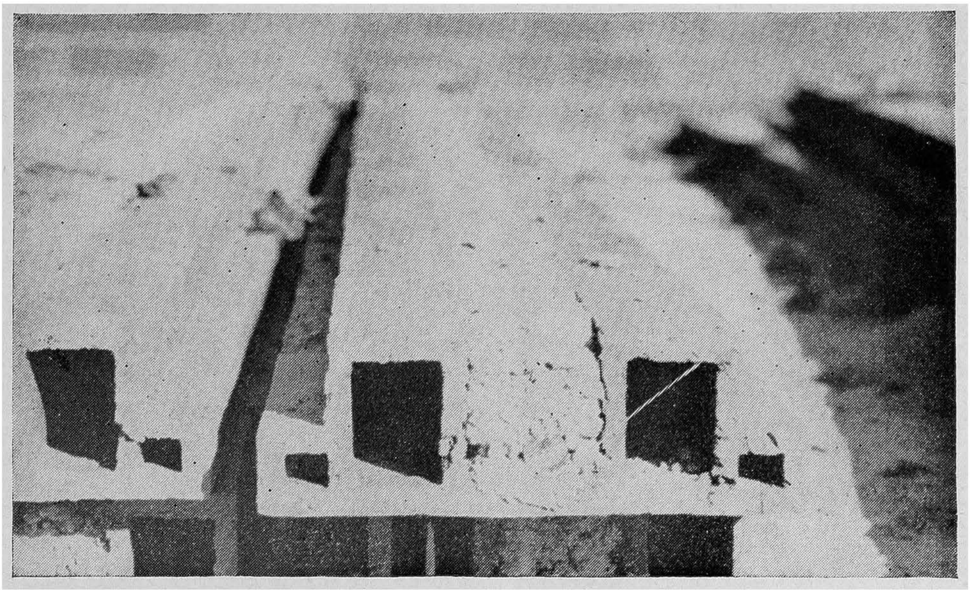


FIG. 4(a). End of precast beam, showing reinforcing steel and concrete cast to top of trough.

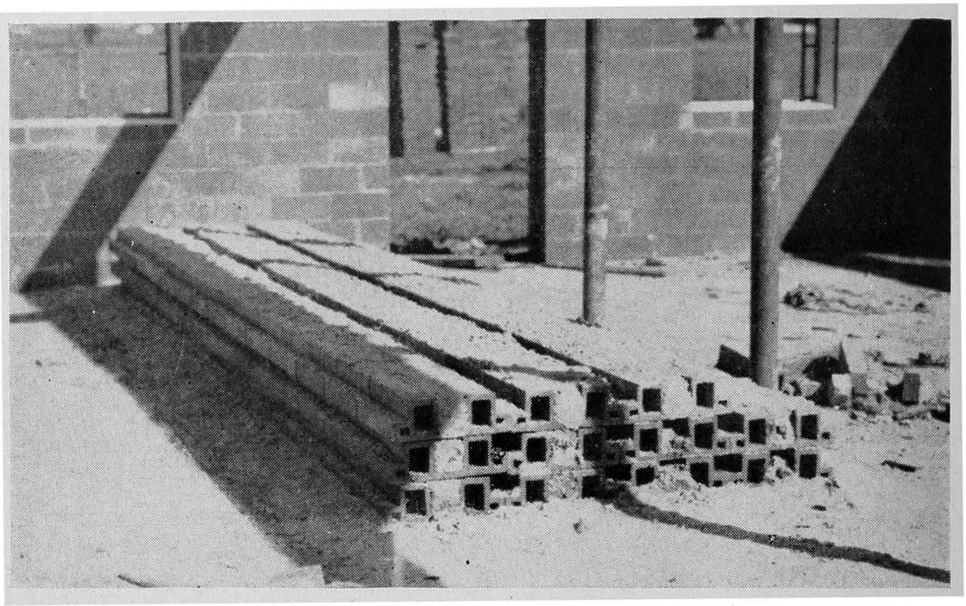


FIG. 4(b). Joistile beams stacked for curing.

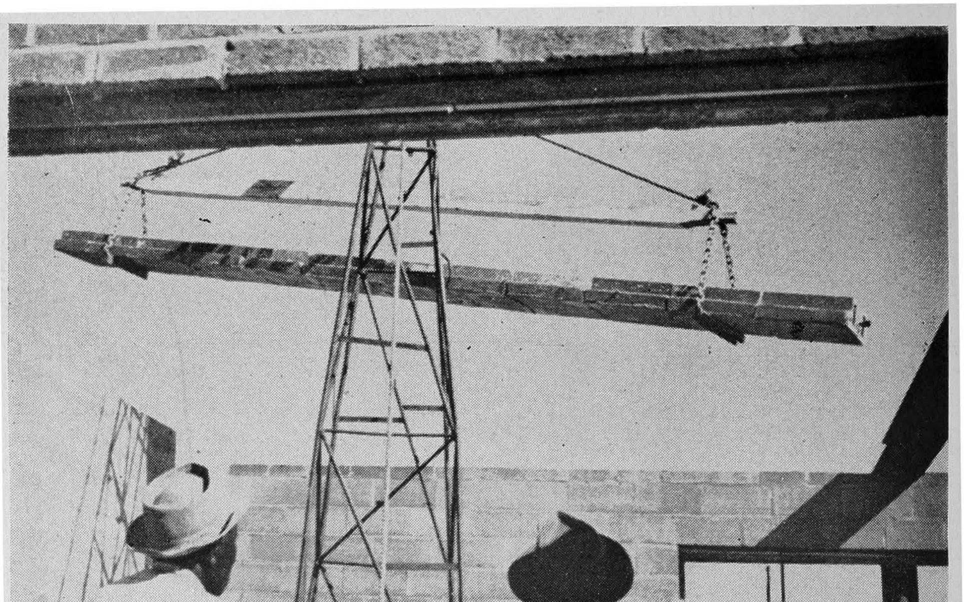


FIG. 5. Beam being hoisted into place after curing.

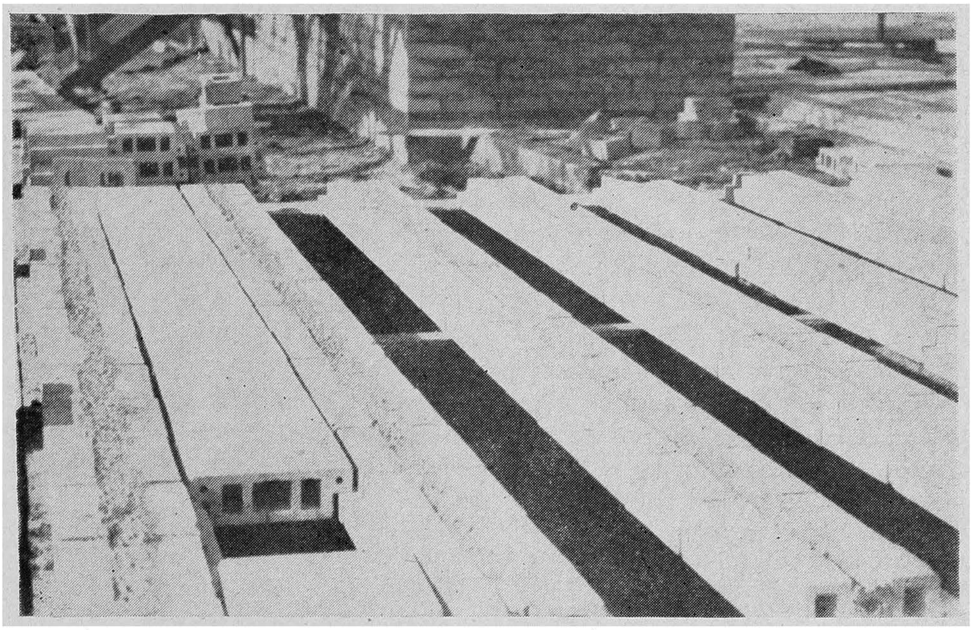


FIG. 6. Top of slab showing the method of placing the filler tile before pouring the concrete topping.

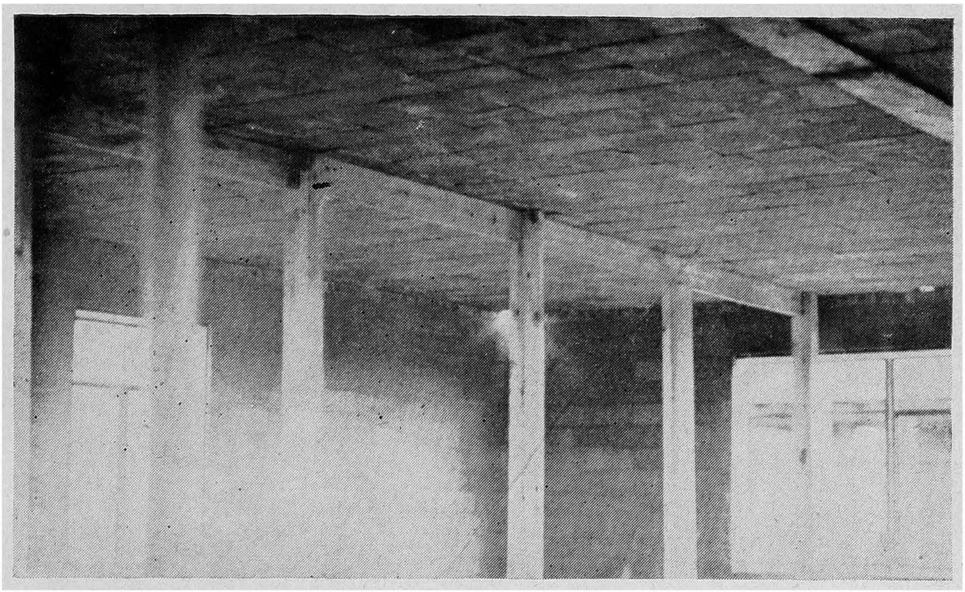


FIG. 7. Under side of slab showing method of placing shoring.

Tile of varying strengths and other properties were obtained from several sources. The physical properties of the various tile were determined, *i.e.*, the tensile and compressive strengths, the moduli of elasticity, and the per cent absorption. Beams and floor slabs using the tile from the several sources were made and tested.

The beams were precast in the same manner as already outlined for construction. Filler tile were cut and placed on each side of the precast beam to form a slab of the width of the center to center dimension of the beam in a structure. A topping of concrete was then poured on this, resulting in a tile-concrete beam and floor slab section. These were then tested to determine the ultimate diagonal tensile resistance.

A movie covering the construction of precast tile-concrete floor systems and the research work reported herein is available at the Visual Instruction Bureau of the Division of Extension of The University of Texas. The film number is 6075. Copies of the film may be purchased on application to The University of Texas.

Conclusions and Recommendations

From the results of these tests on joistile-concrete beams several basic conclusions were developed. The resulting recommendations that are made apply only to the use of joistile:

(1) It was concluded that the proper section to use for designing the beams for resistance to diagonal tension was the width of the concrete stem plus the total thickness of the vertical shells or webs of the beam tile that extend the full depth of the unit. This did not include any section of the filler tile.

(2) If the tile had a strength equal to or greater than the concrete, the tile-concrete beams had a diagonal tensile strength equal to or greater than that of an equivalent concrete beam.

(3) The diagonal tension resistance increased with an increase in compressive strength of tile.

(4) The tile and concrete acted as a unit providing the bond between the tile beam and concrete topping was sufficient.

(5) The design procedure using *joistile* for this type of construction is recommended to be as follows:

(a) For stresses due to moment and deflection, the design shall be the same as specified for concrete by the Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete or the American Concrete Institute Building Code.

(b) For the design for diagonal tension or shear resistance, the procedure established by the above mentioned specifications seems to be too strict. It is recommended that instead of using only the tile shells in contact with the concrete stem, the design shall include all the tile shells or webs of the beam tile that extend the full depth of the unit. This does not include any section of a filler tile and this design procedure applies only to the joistile type of unit. Due to the fact that the concrete stem is much stronger in vertical shear than the beam is in diagonal tension, the requirement of the specifications that the tile joints be staggered is not necessary.

(6) It is recommended that the beams be precast with either a concrete using a "pea" gravel with a maximum size of ⅝ inch or with a rich mortar with a small lime content (not to exceed 25% of the volume of cement).

Physical Properties of Materials Used

CONCRETE

The concrete used throughout the investigation was designed to have a compressive strength of approximately 3,000 pounds per square inch. This required a cement factor of 4.73 sacks per cubic yard and a water factor of 7.67 gallons per sack of cement. Washed river sand and gravel were used to give the optimum mixture with this water and cement. The sand used passed a ¼″ mesh sieve and the gravel used passed a ⅝″ mesh sieve. Normal Portland cement was used. The aggregates, cement and water were weighed to the nearest 0.1 pound. The aggregates and cement were placed in a laboratory mixer and mixed dry before adding the water. After the water was added the concrete was then mixed until a uniform mixture was obtained. One standard ASTM cylinder was made from each batch of concrete. Standard slump tests were made for each batch. Slumps varied from 2″ to 4″ with an average about 2¾″. This slump would be too low for pouring concrete without the use of a mechanical vibrator. For hand vibration the slump should be at least four inches.

The cylinders were cured by covering with wet cement sacks for seven days, and remained in the open until tested. This was the same method of curing as was used for the beams. The compressive strength of these cylinders varied from 2,540 psi to 3,520 psi with an average equal to 3,150 psi.

REINFORCING STEEL

The steel used was ¾ inch round deformed bars of intermediate grade billet steel. Tension tests on the steel gave an average yield point stress of 44,100 psi, an average elongation in eight inches of 21.8 per cent, and an average tensile strength of 77,800 psi.

TILE

The physical properties of the several tile, used in the investigation, which were determined as pertinent to this investigation were: the per cent absorption, compressive strength, modulus of rupture, tensile strength, and modulus of elasticity in tension and compression. These properties for the several tile are given in Table I.

The average absorption was determined by the procedure specified for structural clay tile by ASTM, Designation C112-36.

The compressive strength of the tile was determined by testing specimens cut from the shoulders of the tile. These specimens were approximately two inches square and four inches long. They were capped on both ends with plaster of paris to give plane bearing surfaces and then tested in a hydraulic testing machine to failure. The compressive strength was determined by dividing the ultimate load by the net cross-sectional area.

TABLE NO. I

Physical Properties of Tile Used

Tile	Description of Tile	Absorption* Per Cent	Compressive Strength PSI	Modulus of Rupture PSI	Tensile Strength PSI	Modulus of Elasticity in Comp. PSI×10⁻⁶	Modulus of Elasticity in Tension PSI×10⁻⁶
A	Buff color, dense, very uniform, no pits or cracks.	5.7	12,440	2,630	818	3.0	3.0
B	Red color, light, not very uniform, numerous pits and cracks.	12.2	4,160	1,190	566	2.1	2.7
C	Dark red color, dense uniform, few pits and cracks.	12.7	12,110	1,210	656	2.6	2.3
D	Medium red color, medium weight, non-uniform, number of small rocks and clay balls in the makeup.	8.3	9,900	1,665	604	3.0	3.2

*One hour boil.

The modulus of rupture was determined by testing specimens cut from the tile having approximate dimensions of 2″ x ⅝″ x 12″. These specimens were tested using a span of 7″ and with the load applied at the center of the span through a one-inch round bar resting on a steel plate ¼″ x 1″ x 2″.

The tensile strength of the tile was determined by testing specimens cut from the tile shells. These specimens were cut as shown in Figure 8. This is the size of an ASTM cement mortar briquet except that the mid-section has been lengthened to one inch. These were then tested in a standard ASTM briquet testing machine to failure and the tensile strength determined.

The modulus of elasticity in compression was determined by attaching four SR-4 electric strain gages to the compression specimens and taking corresponding stress-strain readings.

The modulus of elasticity in tension was determined by attaching SR-4 electric strain gages to opposite sides of the tension specimens and taking corresponding stress-strain readings.

TILE-CONCRETE BOND TESTS

An attempt was made to determine the bond strength between the tile and concrete. In this test specimens similar to that shown in Figure 9 were cut from the beams and tested in shear. Due to the fact that the concrete used was a dry mix and that some of the tile still had the "die skin" on it, the results of these tests were too erratic to arrive at any definite conclusions.

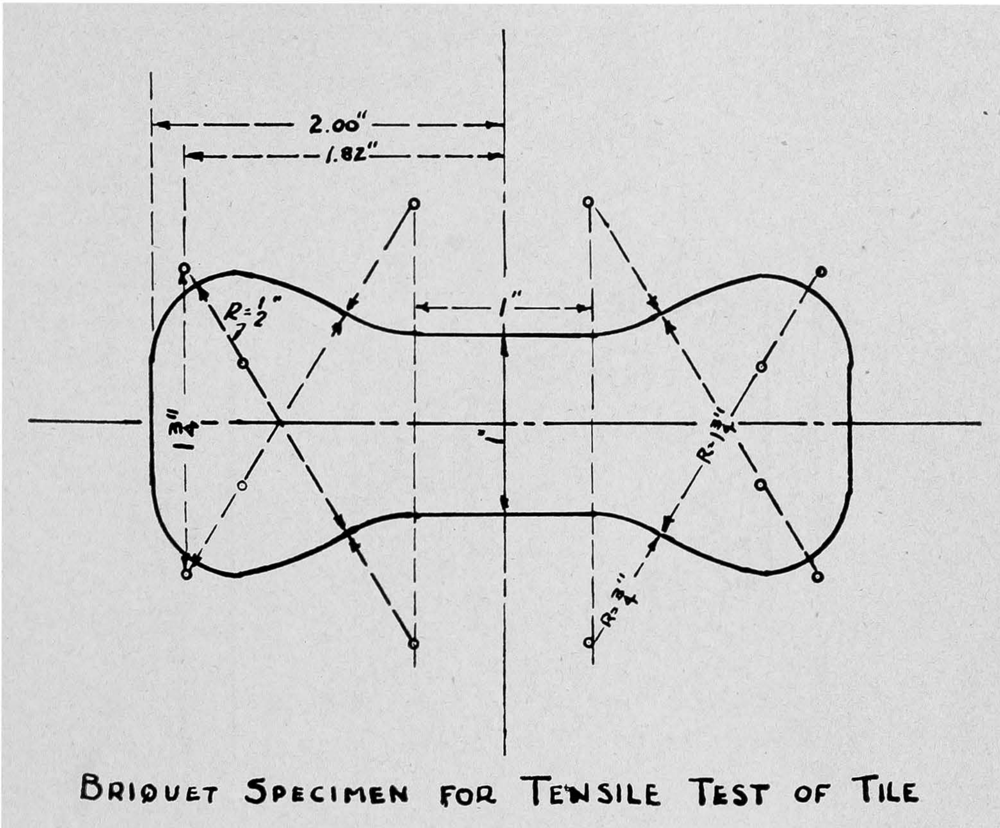
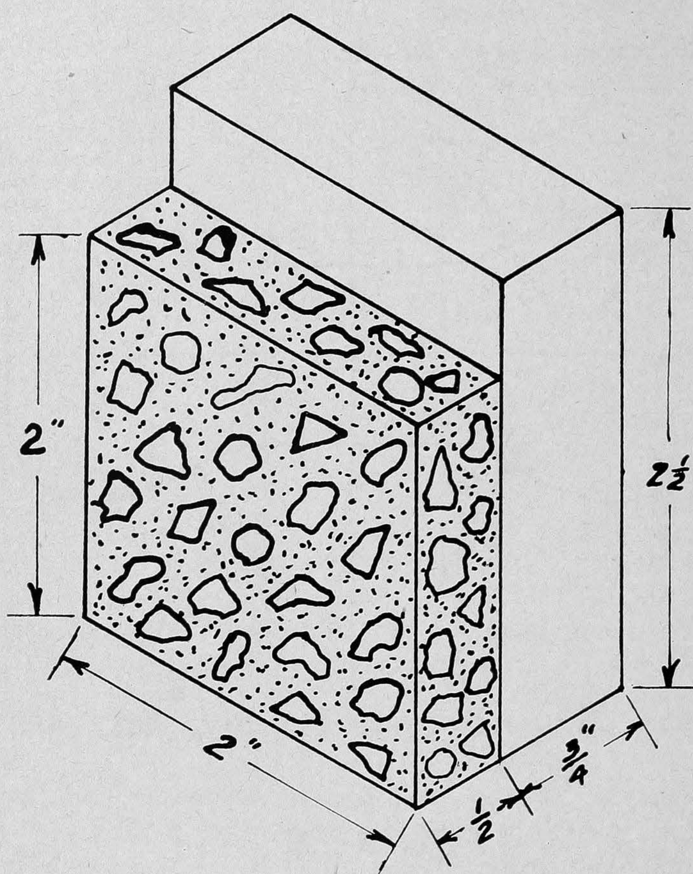


Figure 8

DESIGN OF BEAMS

The reinforced joistile-concrete type of floor construction is in effect a series of T-beams. It is possible to secure two depths of beams depending upon how the spanner tile are placed. These two sections are shown in Figure 2. In the design of these beams, ordinary reinforced concrete T-beam theory is used. The specifications should be either those of the American Concrete Institute Building Code or of the Joint Committee on Recommended Specifications for Concrete and Reinforced Concrete. The specifications provide for a maximum diagonal tension stress by limiting the allowable calculated shear stress. In these specifications, the width of the slab flange used in design is the distance between center lines of the beams and the width of the web is the width of the concrete plus the thickness of the beam tile shells in immediate contact with the web concrete. Since the usual topping thickness used for this type of construction is 1½", the beams were designed with this thickness.



Specimen Used in Tile-Concrete Bond Tests

Figure 9

The resulting design sections for the flush type construction and the heavy type construction are shown in Figure 10.

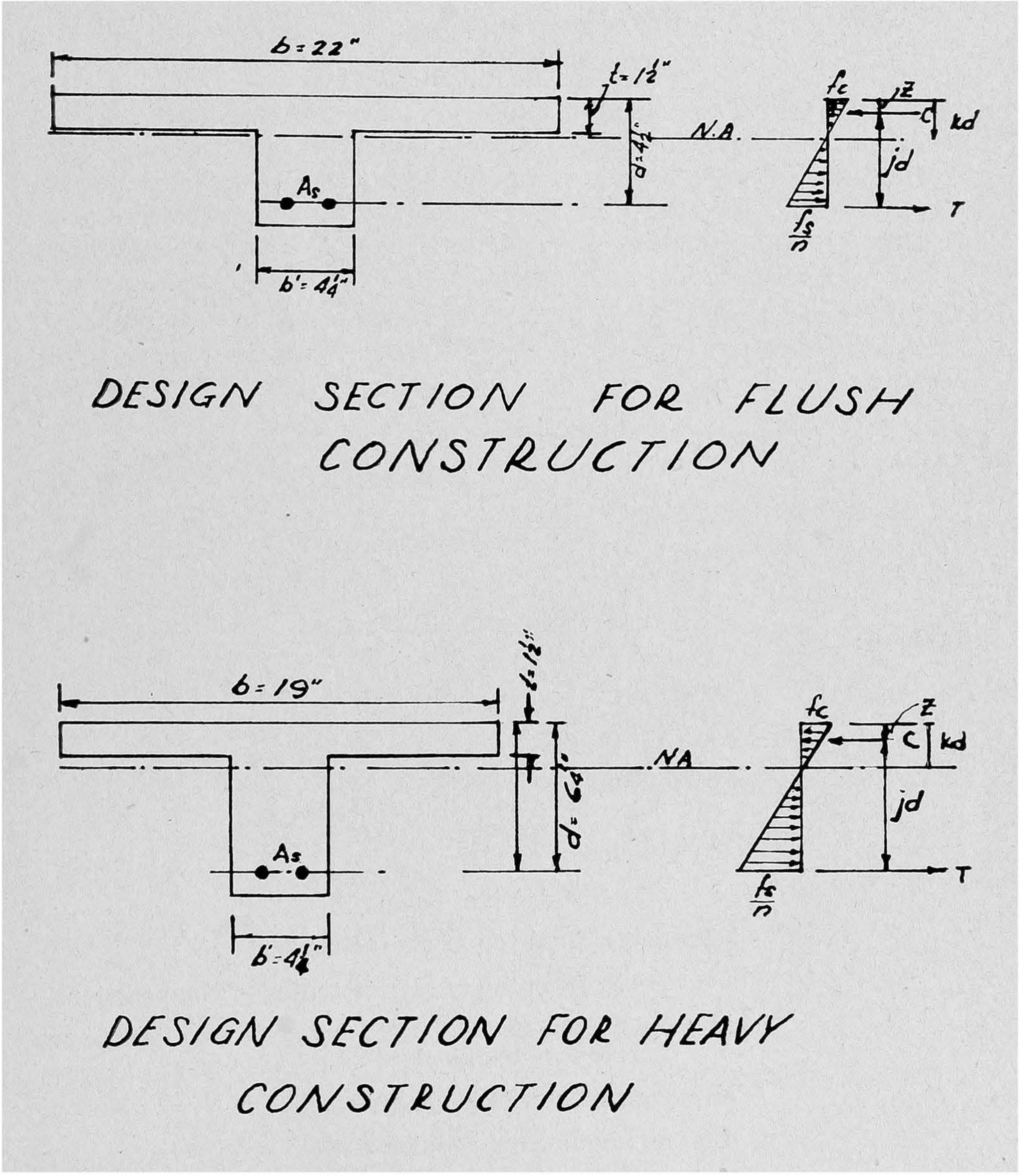


FIGURE 10.

The beams in this test were designed to fail in diagonal tension by:

(1) Using a relatively short span.
(2) Providing sufficient steel to prevent failure in tension.
(3) Providing a flange of sufficient area to prevent failure in compression.
(4) Providing anchorage for the steel to prevent failure in bond.

In the calculation of the stresses in the beams, the following formulas were used:

$$k = \frac{np + \frac{1}{2}(t/d)^2}{np + t/d}$$

$$z = \frac{3\,kd - 2t}{2\,kd - t} \times t/3$$

$$jd = d - z$$

$$f_c = \frac{M}{(1 - t/2kd)\,btjd}$$

$$f_s = \frac{M}{A_s jd}$$

$$v = \frac{V}{\frac{7}{8}\,b'd}$$

$$u = \frac{V}{\Sigma_o\,\frac{7}{8}\,d}$$

Where:

$$n = \frac{E_s}{E_c}$$

$$p = \frac{A_s}{bd}$$

t = thickness of slab
d = effective depth of beam
kd = depth from top of slab to neutral axis
z = depth from top of slab to center of compression
jd = length of moment arm between resultant compression and steel
M = moment due to load applied
f_c = maximum compressive stress in concrete
f'_c = cylinder compressive strength of concrete
f_s = tensile stress in steel
v = calculated shear stress

u = calculated bond stress

V = total shear

Σ_o = perimeter of reinforcing bars

b = width of flange

b' = width of stem

E_c = modulus of elasticity of concrete

E_s = modulus of elasticity of steel

A span of seven feet, with an overall beam length of eight feet, was selected as the most desirable. On the assumption that concrete with a cylinder compressive strength of 3,000 psi would develop a calculated beam shear stress of 200 psi before it failed in diagonal tension, it was determined that two ¾″ round deformed steel bars of the intermediate grade would be needed to assure a failure in diagonal tension.

With the dimensions as shown in Figure 10, and using conventional reinforced concrete design the allowable live load at the third points was calculated as:

Flush Construction

$$A_s = 0.88 \text{ sq. in.}$$

$$t/d = \frac{1.5}{4.5} = 0.333$$

$$p = \frac{0.88}{22 \times 4.5} = 0.00889$$

$$n = \frac{30 \times 10^6}{3 \times 10^6} = 10$$

$$k = \frac{10(0.00889) + \frac{1}{2}(0.333)^2}{10(0.00889) + 0.333} = \frac{0.1445}{0.4222}$$

$$k = 0.342$$

$$kd = 1.54 \text{ inches}$$

$$z = \frac{3(1.54) - 2(1.5)}{2(1.54) - 1.5} \times \frac{1.5}{3} = \frac{1.62}{1.58} \times \frac{1}{2}$$

$$z = 0.51 \text{ inches}$$

$$jd = 4.50 - 0.51 = 3.99 \text{ inches}$$

Design for Shear

Allowable $v = 0.03\, f'_c$

Allowable $v = 0.03 \times 3{,}000 = 90$ psi

Allowable $V = v\, \frac{7}{8}\, b'd$

$$\text{Allowable V} = 90 \times 7/8 \times 4.5 \times 4.25 = 1{,}505 \text{ pounds}$$

Dead load of a concrete beam = 50 pounds per foot

$$\text{Dead load V} = \frac{50 \times 7}{2} = 175 \text{ pounds}$$

Allowable live load V = 1,330

Allowable total live load (at third points) for shear = 2,660 pounds.

Design for Moment

$$M = f_s\, A_s\, jd$$

$$\text{Allowable M} = 20{,}000 \times 0.88 \times 3.99 = 70{,}200 \text{ inch lbs.}$$

$$\text{Dead load M} = \frac{50\ (7)^2 \times 12}{8} = 3{,}700 \text{ inch lbs.}$$

Allowable live load M = 66,500 inch lbs.

Allowable total live load based on Moment $= \dfrac{65{,}500 \times 2}{28} =$ 4,750 lbs. when loaded at third points (28″ from supports)

Design for Bond

$$\text{Allowable u} = 0.05\ f'_c$$

$$\text{Allowable u} = 0.05 \times 3{,}000 = 150 \text{ psi}$$

$$\text{Allowable V} = u\ 7/8\ d\Sigma_o$$

$$\text{Allowable V} = 150 \times 4.5 \times 7/8 \times 4.71$$

$$\text{Allowable V} = 2{,}775 \text{ lbs.}$$

Dead load V = 175 pounds

Allowable total live load (at third points) for bond = 5,200 pounds

With proper anchorage provided the allowable bond stress may be increased by 50 per cent. Thus, the shear stress would limit the allowable live load on a beam of this type using conventional design procedure to 2,660 pounds.

Heavy Construction

$$A_s = 0.88 \text{ sq. in.}$$

$$t/d = \frac{1.5}{6.25} = 0.24$$

$$p = \frac{0.88}{19 \times 6.25} = 0.00741$$

$$n = 10$$

$$k = \frac{10\ (0.00741) + \frac{1}{2}\ (0.24)^2}{10\ (0.00741) + 0.24} = \frac{0.1029}{0.3141}$$

$$k = 0.327 \text{ inches}$$

$$kd = 2.041 \text{ inches}$$

$$z = \frac{3(2.04) - 2(1.5)}{2(2.04) - 1.5} \times \frac{1.5}{3} = \frac{3.12}{2.58} \times \frac{1}{2} = 0.60 \text{ in.}$$

$$jd = 6.25 - 0.60 = 5.65 \text{ inches}$$

Design for Shear

Allowable V = 90 × ⅞ × 6.25 × 4.25 = 2,090 pounds.

Dead load of a concrete beam = 60 lbs. per foot.

$$\text{Dead load V} = \frac{60 \times 7}{2} = 210 \text{ pounds}$$

Allowable total live load (at third points) for shear = 3,760 pounds

Design for Moment

Allowable M = 20,000 × 0.88 × 5.65 = 99,400 inch pounds

$$\text{Dead load M} = \frac{60\ (7)^2 \times 12}{8} = 4{,}400 \text{ inch pounds.}$$

Allowable live load M = 95,000 inch pounds

$$\text{Allowable total live load based on Moment} = \frac{95{,}000}{28} \times 2 =$$

6,790 pounds when loaded at the third points (28″ from supports)

Design for Bond

Allowable V = 150 × 4.71 × ⅞ × 6.25 = 3,880 pounds.

Dead load V = 210 pounds

Allowable total live load (at third points) for Bond = 7,340 pounds

With proper anchorage provided the allowable bond stress may be increased by 50 per cent.

Thus the shear stress would limit the allowable live load on a beam of this type using conventional design procedure to 3,760 pounds.

METHOD OF CONSTRUCTION

Six groups of beams were constructed as follows:

Group H—Twelve tile-concrete beams of the flush type of construction shown in Figure 11 (three beams with each tile source).

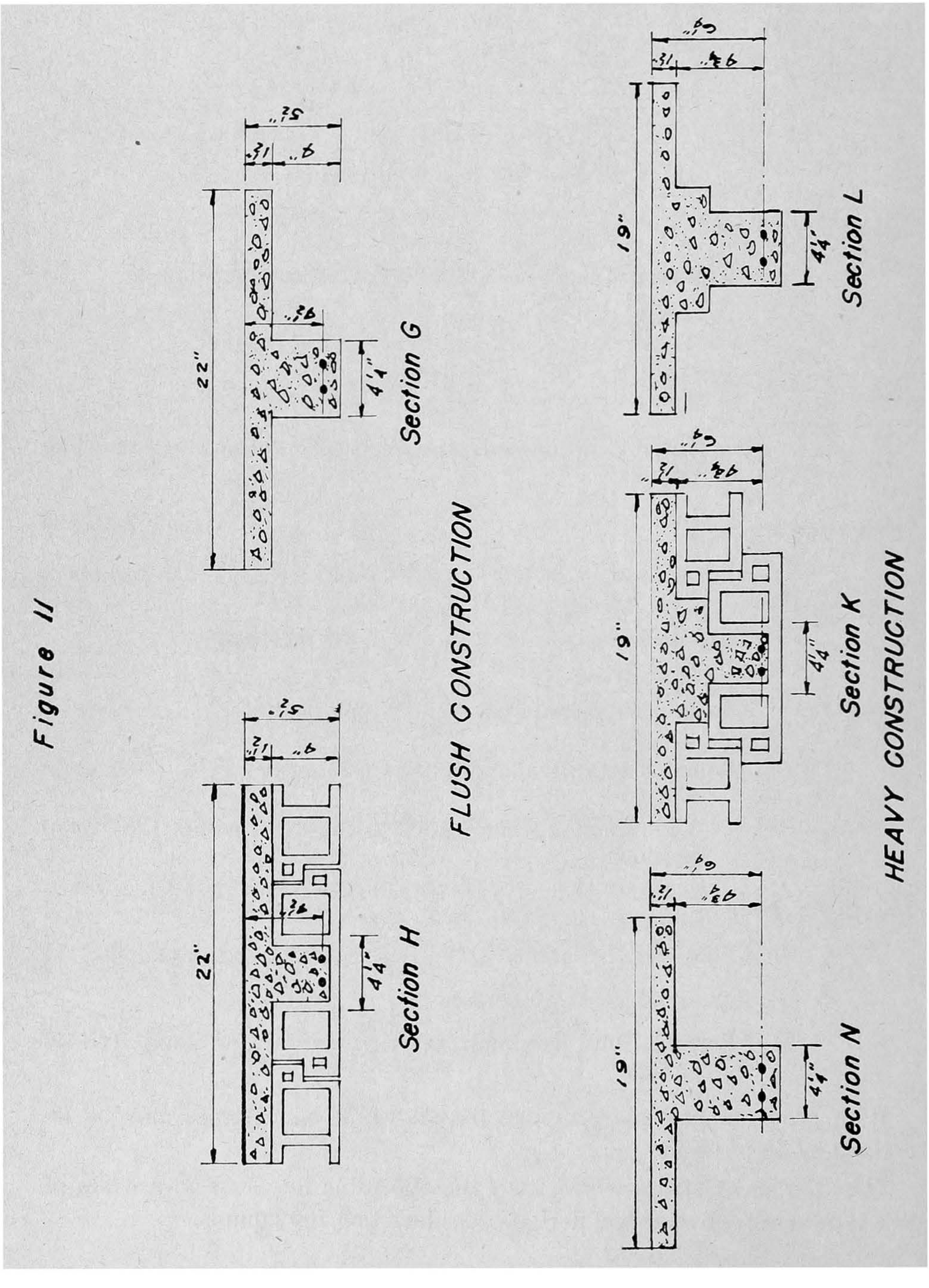


Figure 11

Group G—Three concrete beams equivalent to the flush type section shown in Figure 11.

Group K—Twelve tile-concrete beams of the type of construction shown in Figure 11 (three beams with each tile source).

Group L—Three concrete beams equivalent to heavy type section shown in Figure 11.

Group N—Three concrete beams equivalent to heavy type section shown in Figure 11.

Group R—Three tile concrete beams of tile "A" equivalent to the flush-type of construction of Group H using mortar for precasting.

In constructing the tile-concrete beams, the tile were laid alongside a timber straight edge on a firm flat surface. The tile were moistened until they were saturated. The surface was allowed to dry; then steel was placed in the bottom of the trough formed by the tile and concrete was placed in the trough and worked around the reinforcing bars. As the trough was filled with concrete it was vibrated with a mechanical vibrator; these precast sections were then cured by covering with wet cement sacks for two days. The spanner tile were cut into halves and placed on each side of the precast beam forming a slab of the proper width. The beam and flange tile were also moistened as described above and the concrete topping was poured. Timber forms were used to hold the topping concrete in place. The slab was then vibrated to a smooth finish with a mechanical vibrator and hand troweled. The beams were then cured under wet cement sacks for seven days.

The beams of Group R were poured in the same manner as the others except that a cement, lime and sand mortar with a 1:¼:3 ratio was used for precasting the beams and the beams of this group were rodded by hand instead of using a mechanical vibrator.

Timber forms of the proper section were used to construct the concrete beams.

The reinforcing bars and the concrete were placed in the same manner as in the construction of the tile-concrete beams. The beams were then cured under wet cement sacks for seven days.

METHOD OF LOADING

All beams were loaded in a similar manner. A test platform was built of steel girders welded together and resting on concrete block supports. A yoke of two steel I-beams as cross pieces connected by steel channels was used to apply the load. This test platform and yoke with a beam in place are shown in Figures 12 and 13.

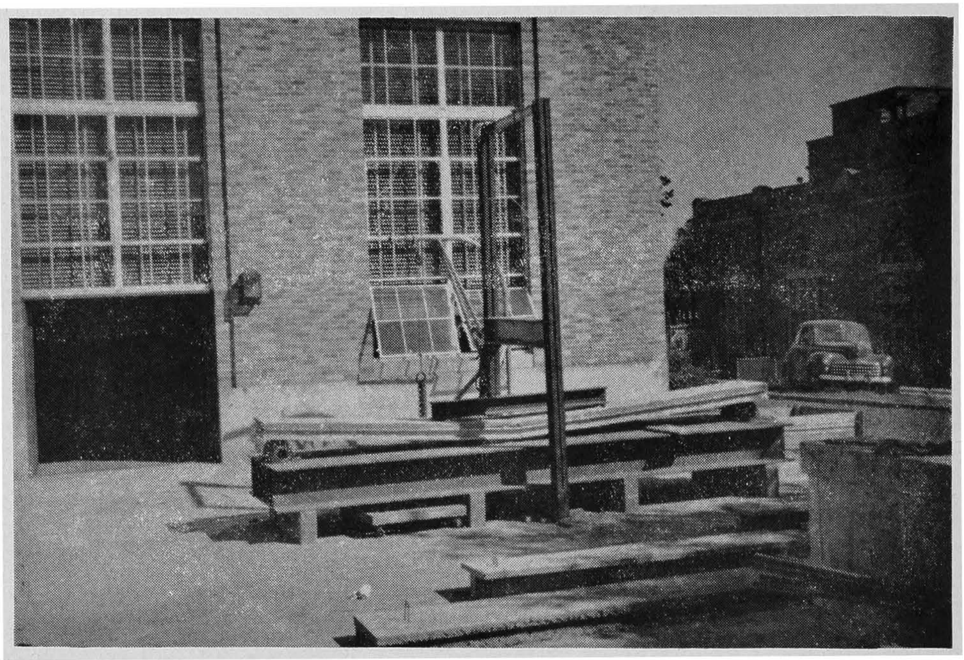


FIG. 12. Side view of the Loading Platform.

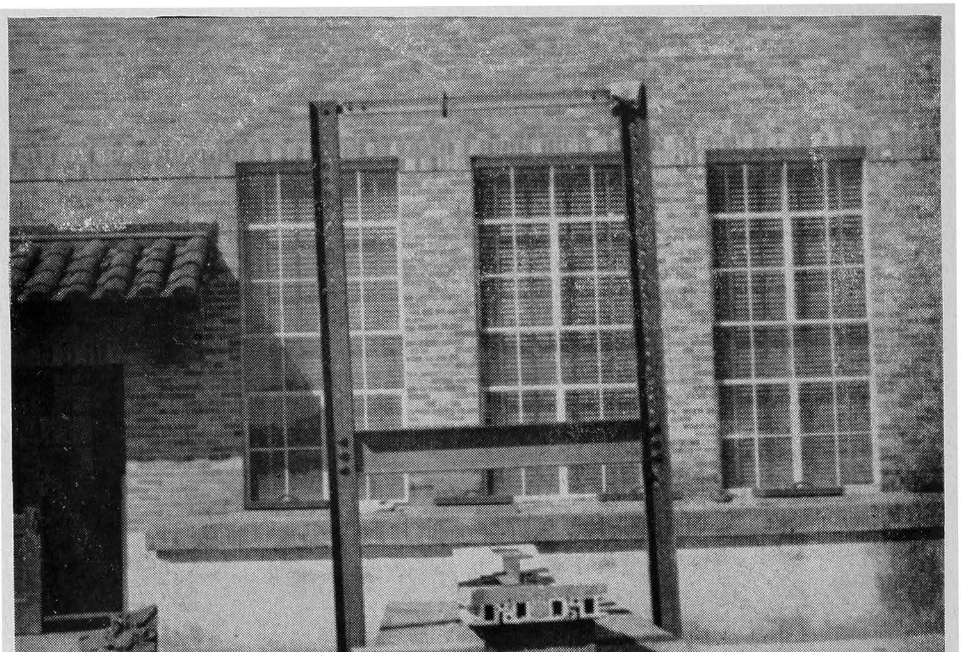


FIG. 13. Front view of Loading Platform.

The test beams were supported on cast iron supports with curved contact edges. One of the supports rested on one-inch round bars and the other rested on a one-inch steel plate. The load was applied by means of a calibrated hydraulic jack with a pressure gage resting on a steel I-beam which transferred the load to the third points of the test beams through ¾″ square steel bars imbedded in plaster of paris to give a uniform bearing surface.

TEST AND RESULTS

All beams were tested in a similar manner in order to make a comparative analysis of the results with as few variables in the testing procedure as possible. They were loaded as previously explained. The loading diagrams and cross-sections of each group of beams are shown in Figures 14, 15, 16, 17, and 18. The beams of Group R had the same loading diagram as the beams of Group H. During the tests, four types of observations were made: (1) The deflection at the midpoint of the beam; (2) The slip between the beam tile and concrete slab; (3) The failing load; (4) The type of failure.

The beams were designed to fail in diagonal tension. However, beam H-3, one of the first beams tested, failed by bond on the steel. This bond failure occurred at a bond stress about 50 per cent greater than the design stress for bars with no anchors. After this failure anchors were provided for the steel and no further bond failures occurred. All other failures were diagonal tension except those of the flush type construction of the tile from source C, and beam R-1. The flush type tile-concrete beams made of tile from source C failed in bond between the beam tile and the flange concrete. These failures were caused by the fact that the "die skin" had not been removed from the top of the beam tile and by the dry concrete mix. However, with this same tile in the heavy construction where the concrete was considerably deeper over the beam tile, no bond failure was observed. Beam R-1 failed in bond between the tile and concrete directly over the support. This was probably due to not having enough overhang to develop the bond stress needed at this point.

Typical failures for all types of beams are shown in Figures 19, 20, 21, 22, 23, 24, and 25.

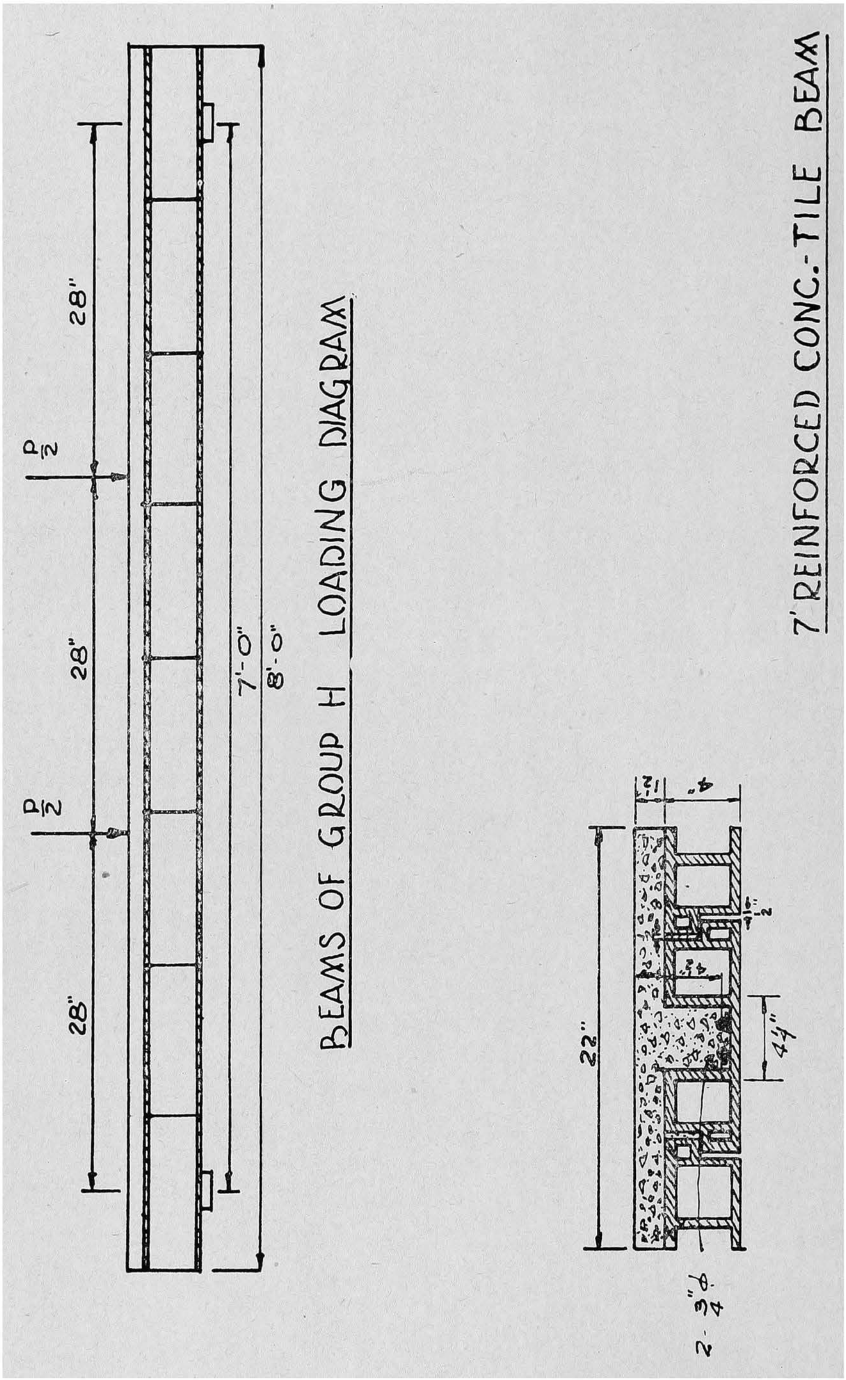

28"
28"
28"
P/2
P/2
7'-0"
8'-0"
BEAMS OF GROUP H LOADING DIAGRAM
22"
4½"
2-¾"φ
7' REINFORCED CONC.-TILE BEAM

FIGURE 14.

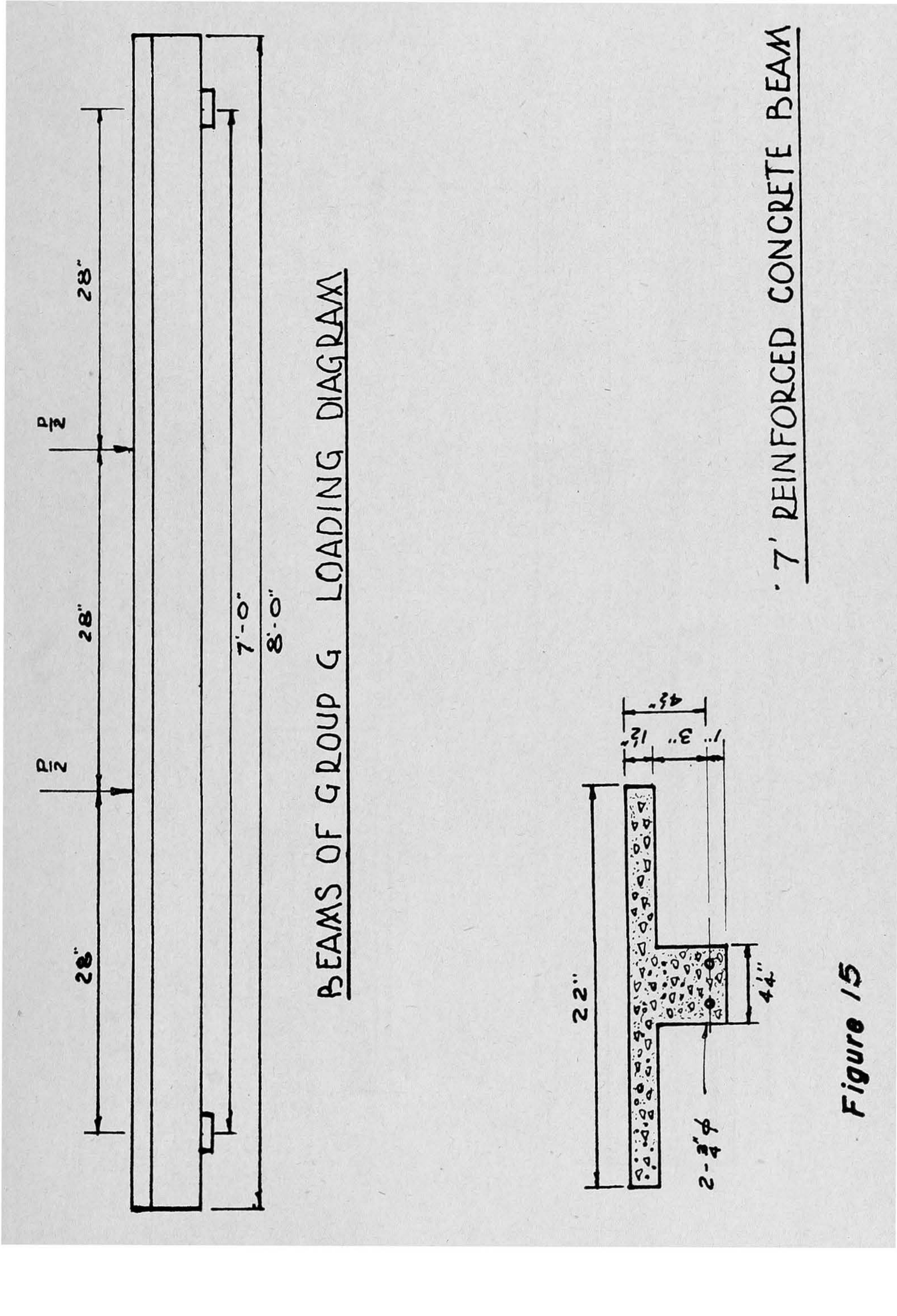
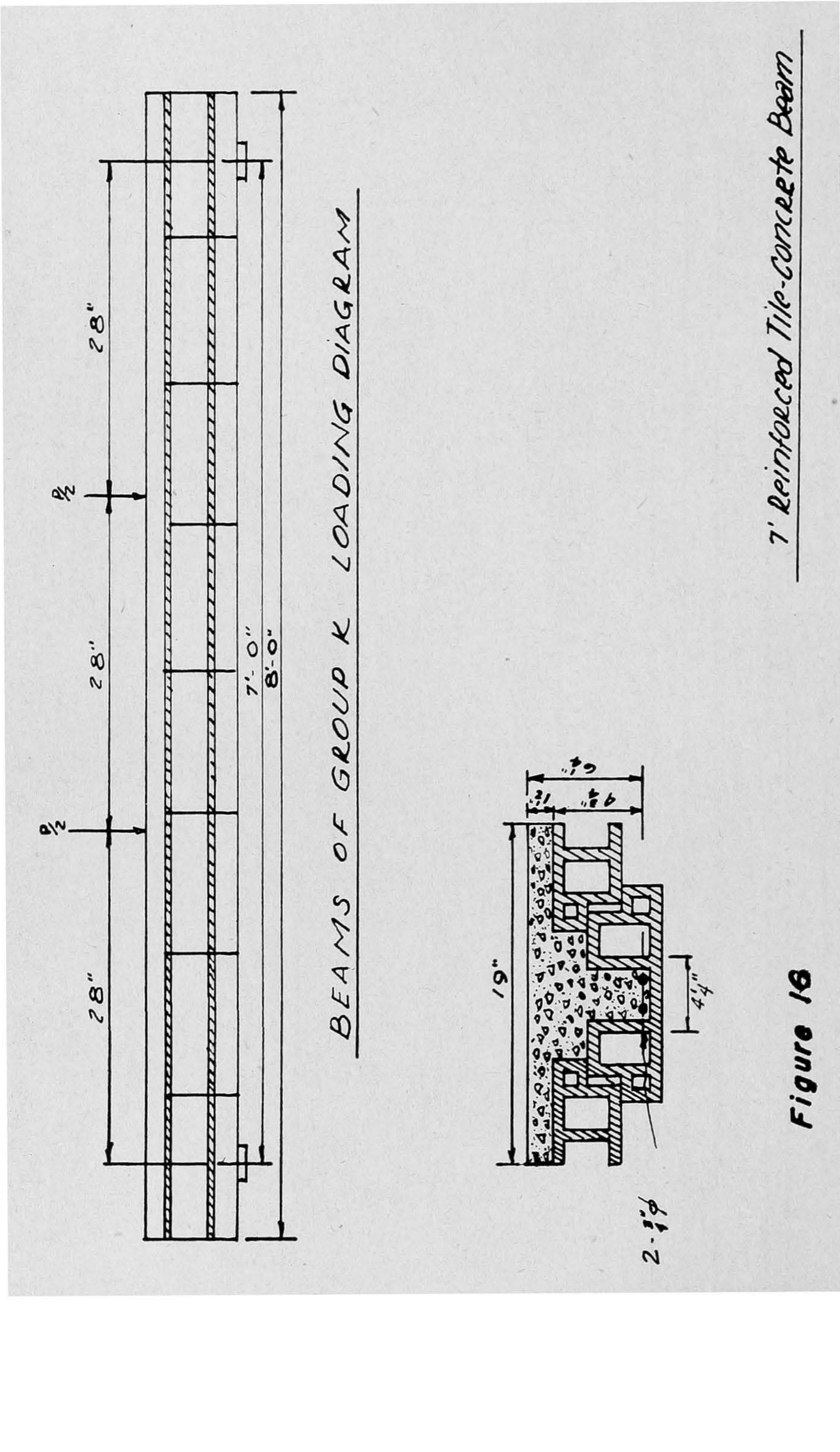

28"
28"
28"
P/2
P/2
7'-0"
8'-0"
BEAMS OF GROUP G LOADING DIAGRAM
22"
1½"
3"
1"
4½"
4¼"
2-¾"φ
'T' REINFORCED CONCRETE BEAM

Figure 15



BEAMS OF GROUP K LOADING DIAGRAM
P/2
P/2
28"
28"
28"
7'-0"
8'-0"
7' Reinforced Tile-Concrete Beam
19"
4¼"
2-3/4" φ

Figure 16

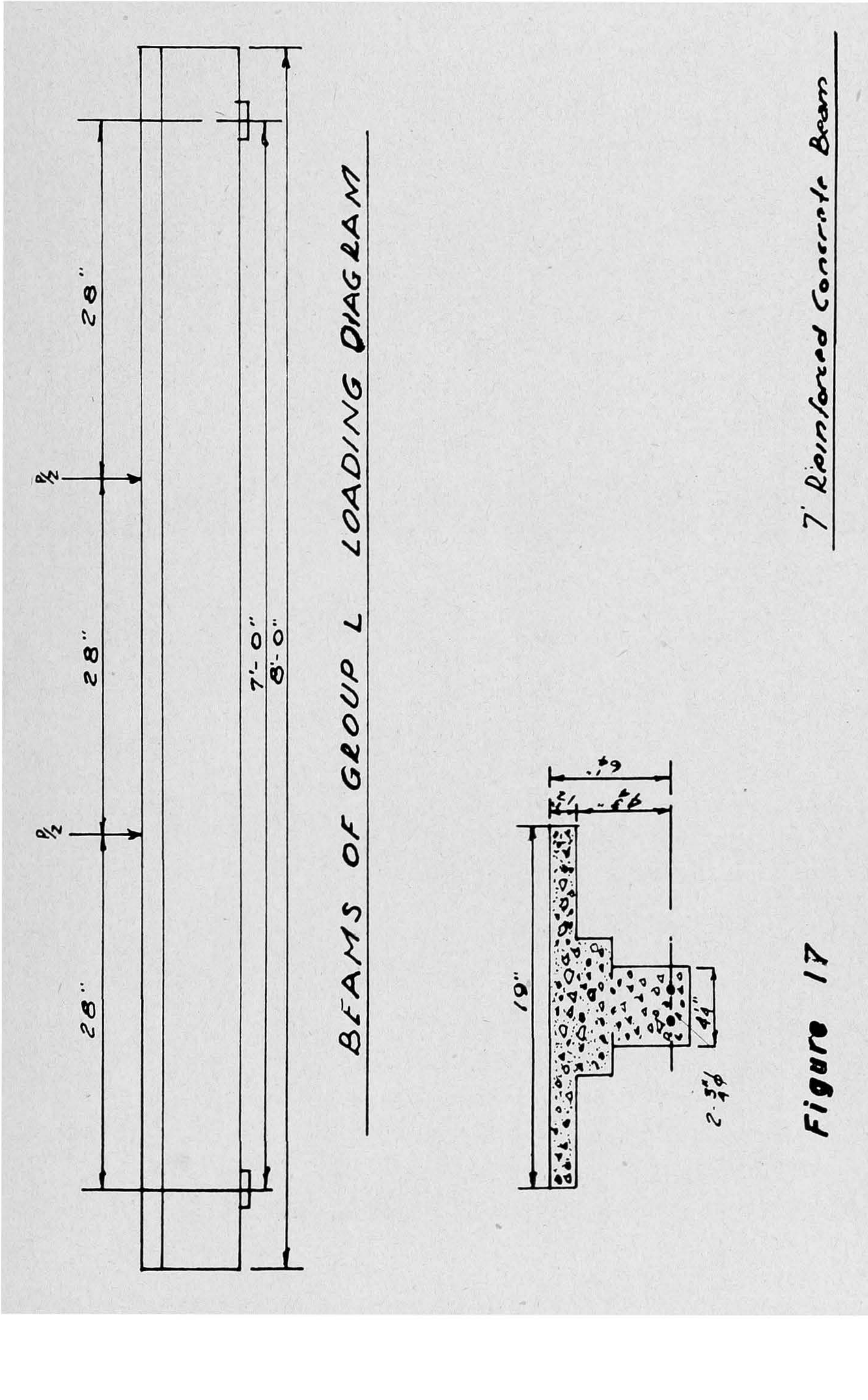

BEAMS OF GROUP L LOADING DIAGRAM
28"
28"
28"
P/2
P/2
7'-0"
8'-0"
19"
4"
7' Reinforced Concrete Beam

Figure 17

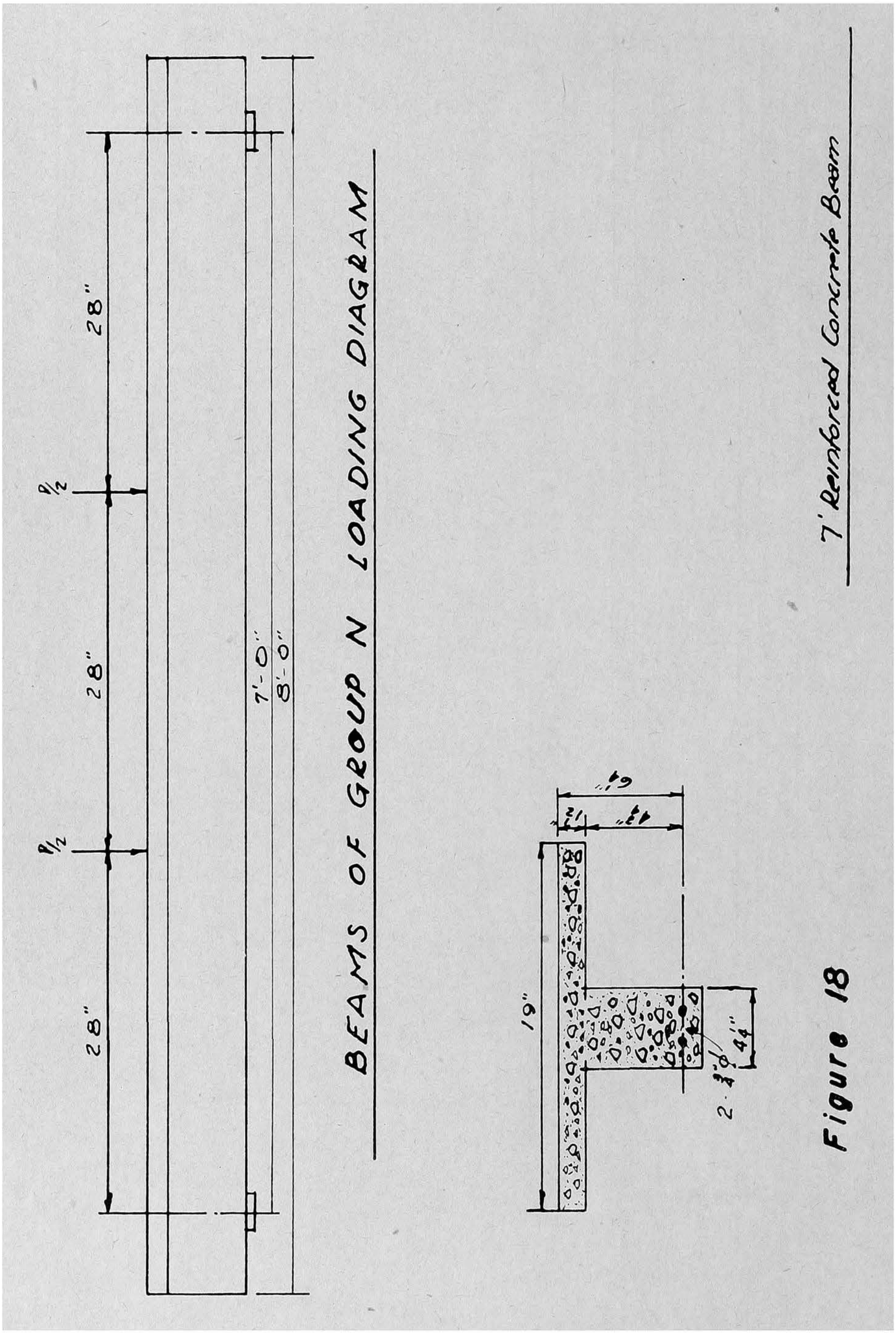


Figure 18

7' Reinforced Concrete Beam

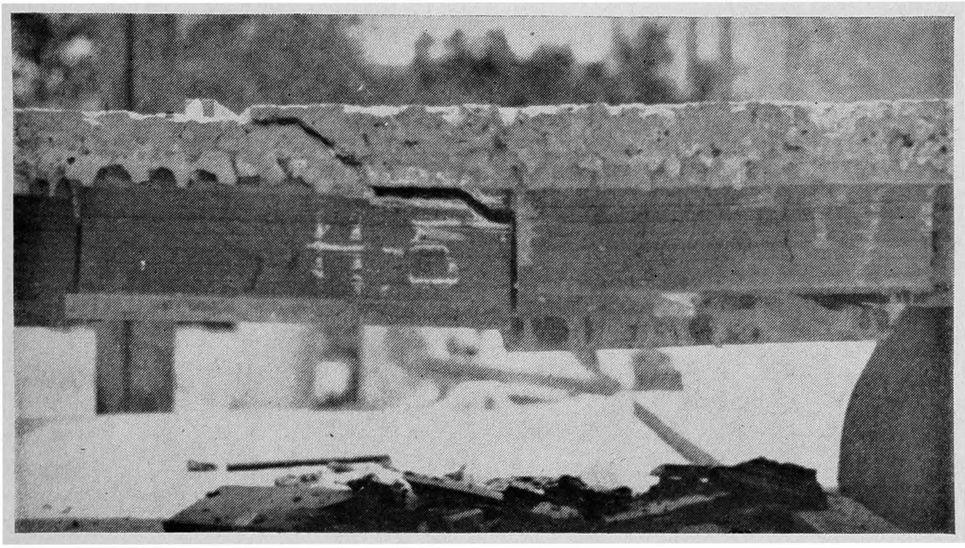


FIG. 19 (a). The condition of the flange tile after failure has taken place. This type of failure was typical of Tile B which was a low strength tile.

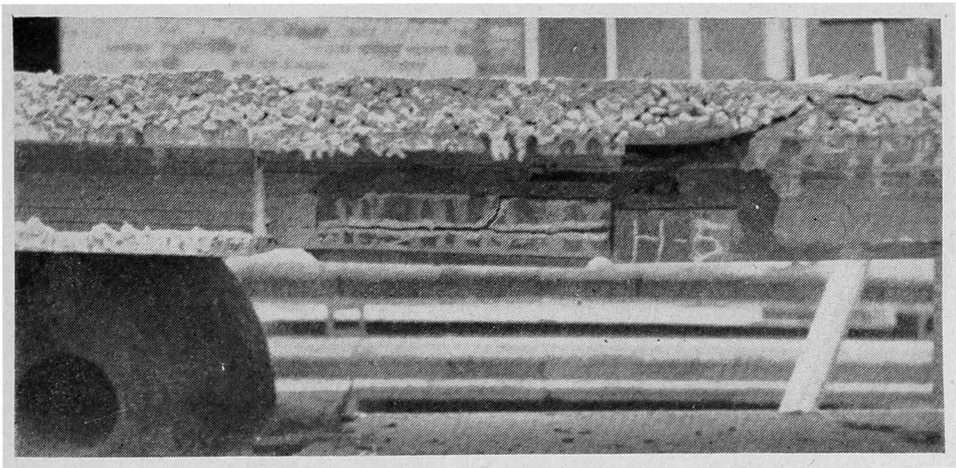


FIG. 19 (b). The same beam as in Fig. 19 (a), after the flange tile was removed showing the condition of the beam tile. Note that the failure cut across the vertical joint.

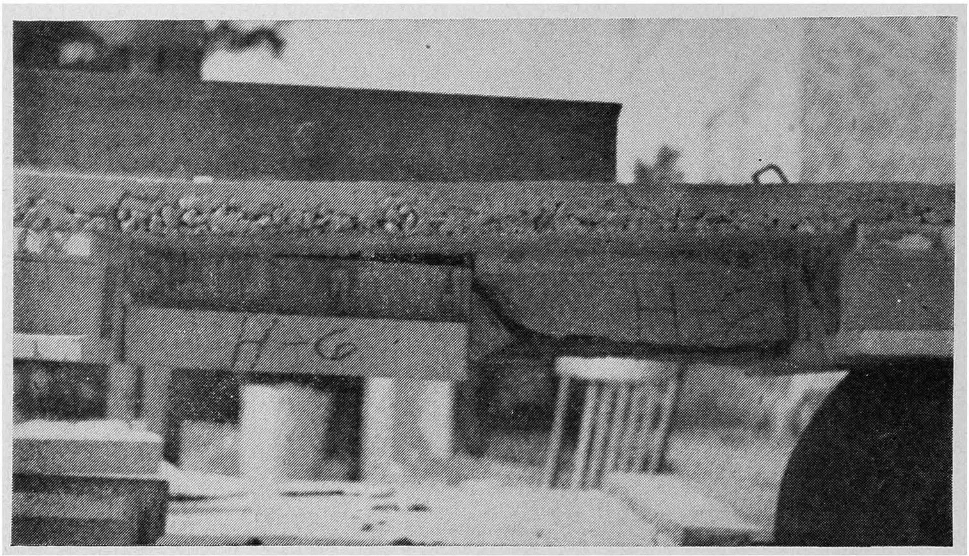


FIG. 20(a). Typical condition of the beam tile in the beams made from Tile A, which was a high strength tile. Note that plane failure follows along top of beam tile, indicating that with the stronger tile the bond between the tile and the concrete and the shear strength were about the same.

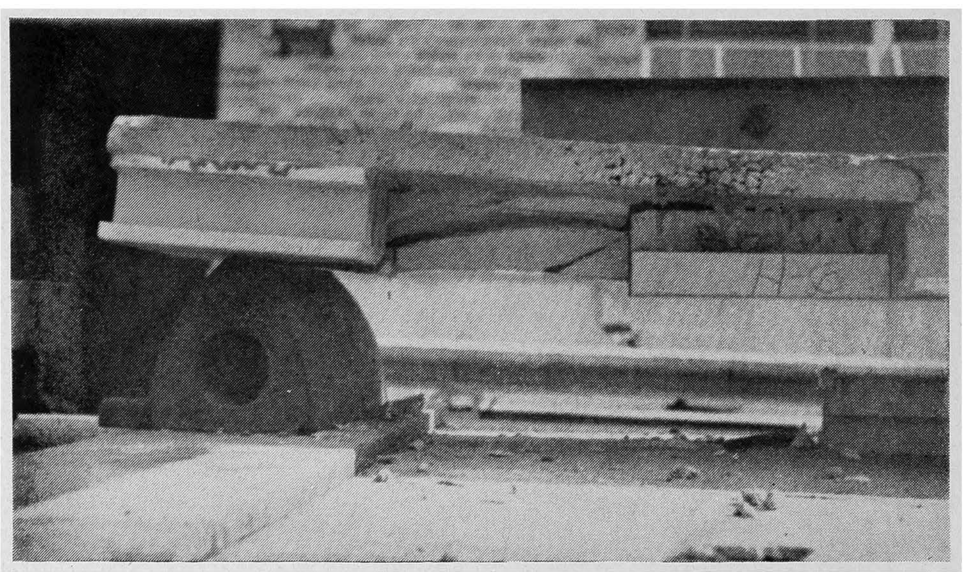


FIG. 20(b). Opposite side of the same beam shown in Fig. 20(a).

FIG. 21 (a). Typical failure of beams of Tile C. Note the tile-concrete bond failure.

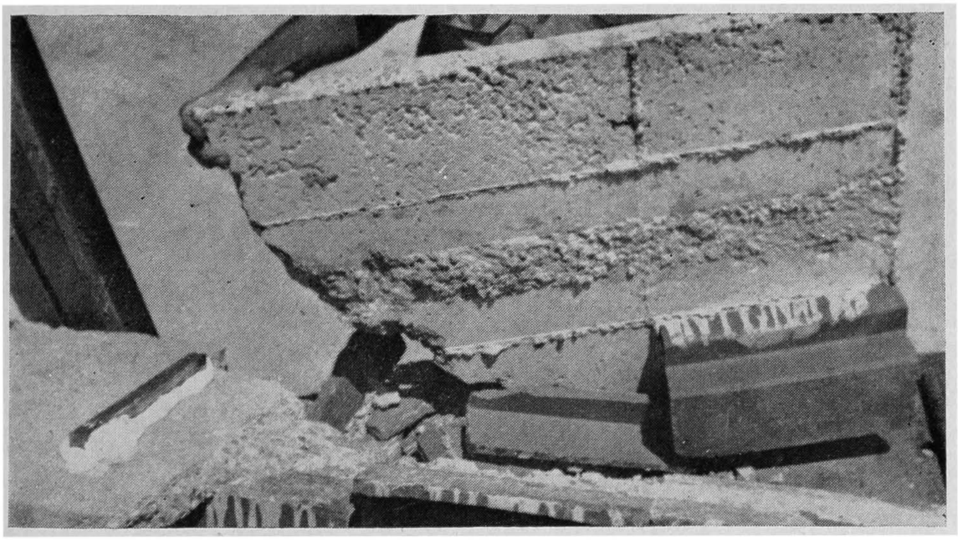


FIG. 21 (b). The concrete slab released completely from Tile C as is shown here.

FIG. 22(a). Typical failure of heavy type beams made from Tile A. Note the plane of failure is very similar to the joistile beams failure.

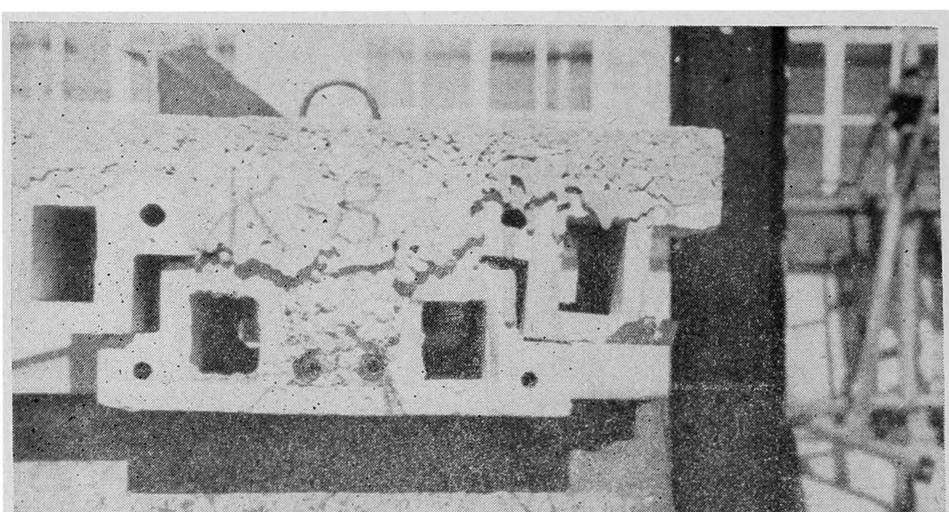


FIG. 22(b). Condition of the end of the beams after failure.

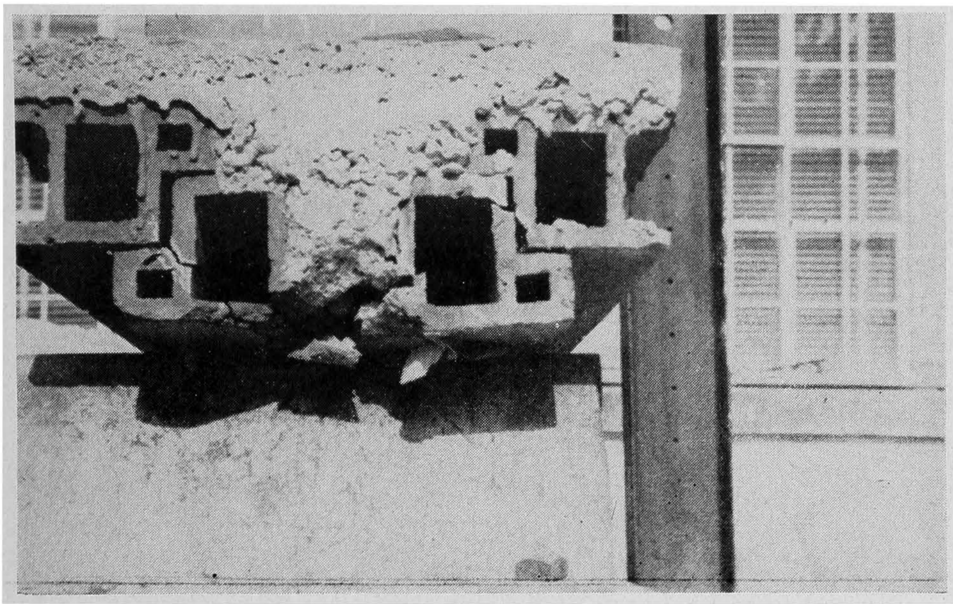


FIG. 23(a). Typical end failure of heavy type beams from Tile B. Note splitting of tile.

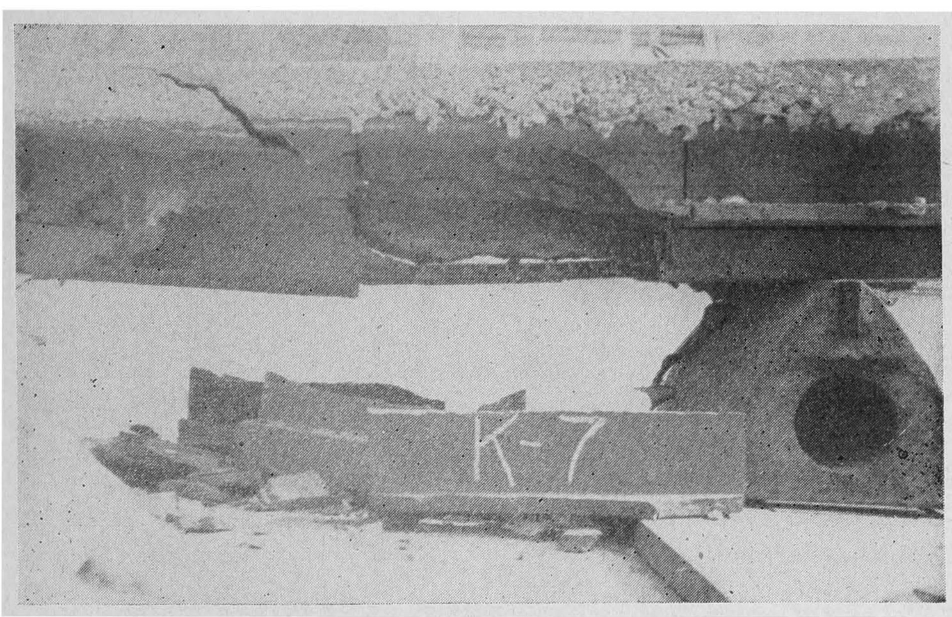


FIG. 23(b). Typical failure of heavy type beams from Tile B.

FIG. 24(a). Typical failure of heavy type beams made from Tile C. Note that here there was no bond failure between tile and concrete as was the case of joistile beams using this same tile.

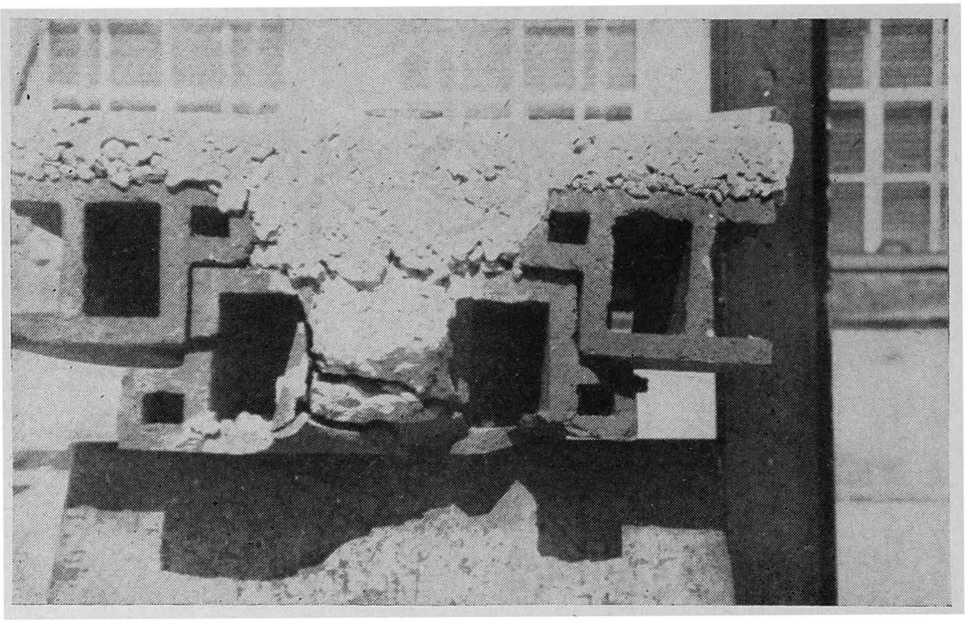


FIG. 24(b). Typical end failure of heavy type beams of Tile C.

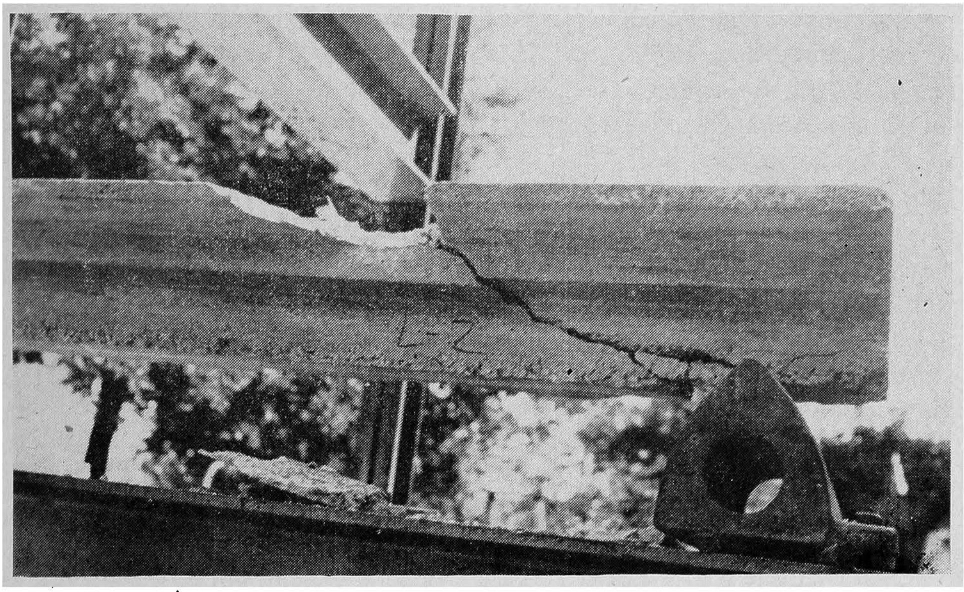


FIG. 25(a). Typical failures of concrete beams. Note failing plane very similar to those of the tile beams. All concrete beams failed in similar manner.

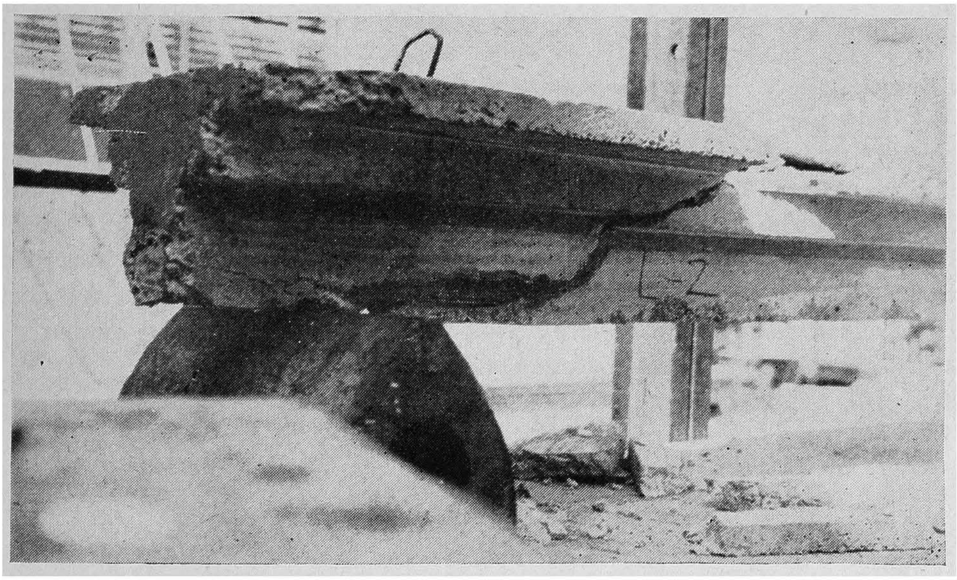
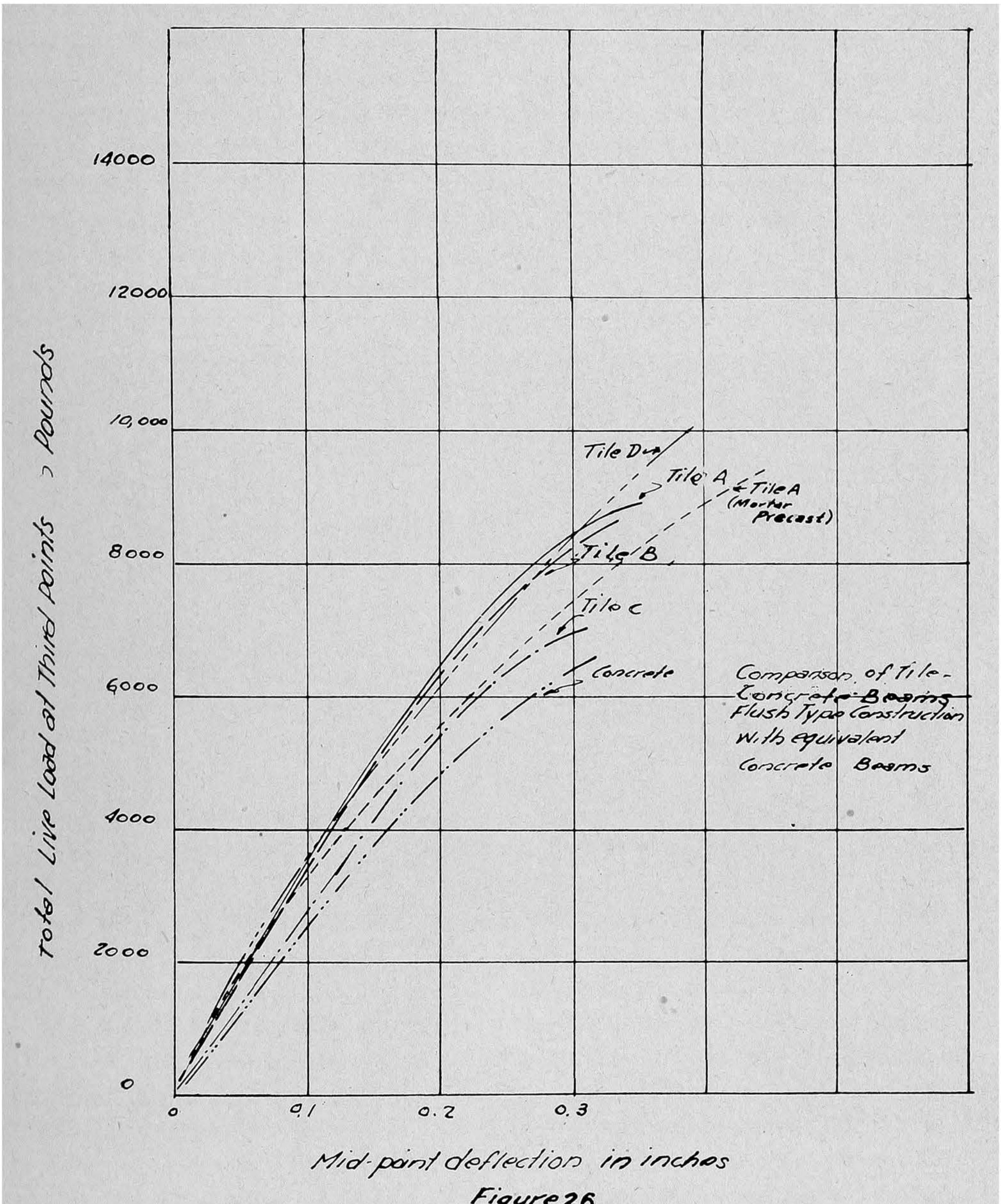


FIG. 25(b). Opposite side of beam shown in Fig. 25(a).

It can be seen from these pictures that the composite beam (except for the above mentioned bond failures) fails as a unit much like the corresponding concrete beams. This indicates that the average bond between the tile and concrete was sufficient. As can be seen from Figure 21, the failure of the beams using tile from source C was by bond between the tile and concrete, which it is believed would not have occurred had the "die skin" been removed or had the concrete mix been more workable. Since the spanner tile has no structural resistance due to the manner in which it is placed in the beam, it was generally removed before pictures were taken. However, Figure 19, is a picture showing the condition of tile B in the spanner tile. Generally speaking the spanner tile of the strongest tiles A and C did not fail when the beam failed. As was found in regard to the "U" type tile beams the pictures indicate that the tile joints are not a plane of weakness in vertical shear and there would be no need for staggering the tile joints as is recommended by the Joint Committee on Recommended Specifications for Concrete and Reinforced Concrete.

Throughout the tests corresponding live load and midpoint deflection readings were taken. Average live load-deflection curves are shown in Figures 26 and 27. From a study of these average curves, it can be seen by comparing those of group G with those of group H and the ones of group K with those of groups L and N that the tile itself adds to the stiffness of the beams. Due to an error in placing the steel in the beams of group N at a depth of seven inches instead of the intended 6¼ inches, this group appears as stiff as the tile-concrete beams. Therefore, the average deflection curve for this group had to be corrected for a depth of 6¼ inches. This difference in deflections is approximately 30 per cent between the tile-concrete beams and the concrete beams of an equivalent design section. This difference does not hold true for the flush type beams of tile C which failed in bond between the tile and the concrete. From these curves, it can be seen that there is no material difference between the deflections of the tile-concrete beams of different tile except for the tile C flush construction beams. This would indicate that the increased stiffness is a result of the increased section due to the tile.



14000
12000
10,000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
Total Live Load at Third Points > Pounds
Mid-point deflection in inches
Tile D
Tile A
Tile A (Mortar Precast)
Tile B
Tile C
Concrete
Comparison of Tile-Concrete Beams Flush Type Construction With equivalent Concrete Beams

Figure 26

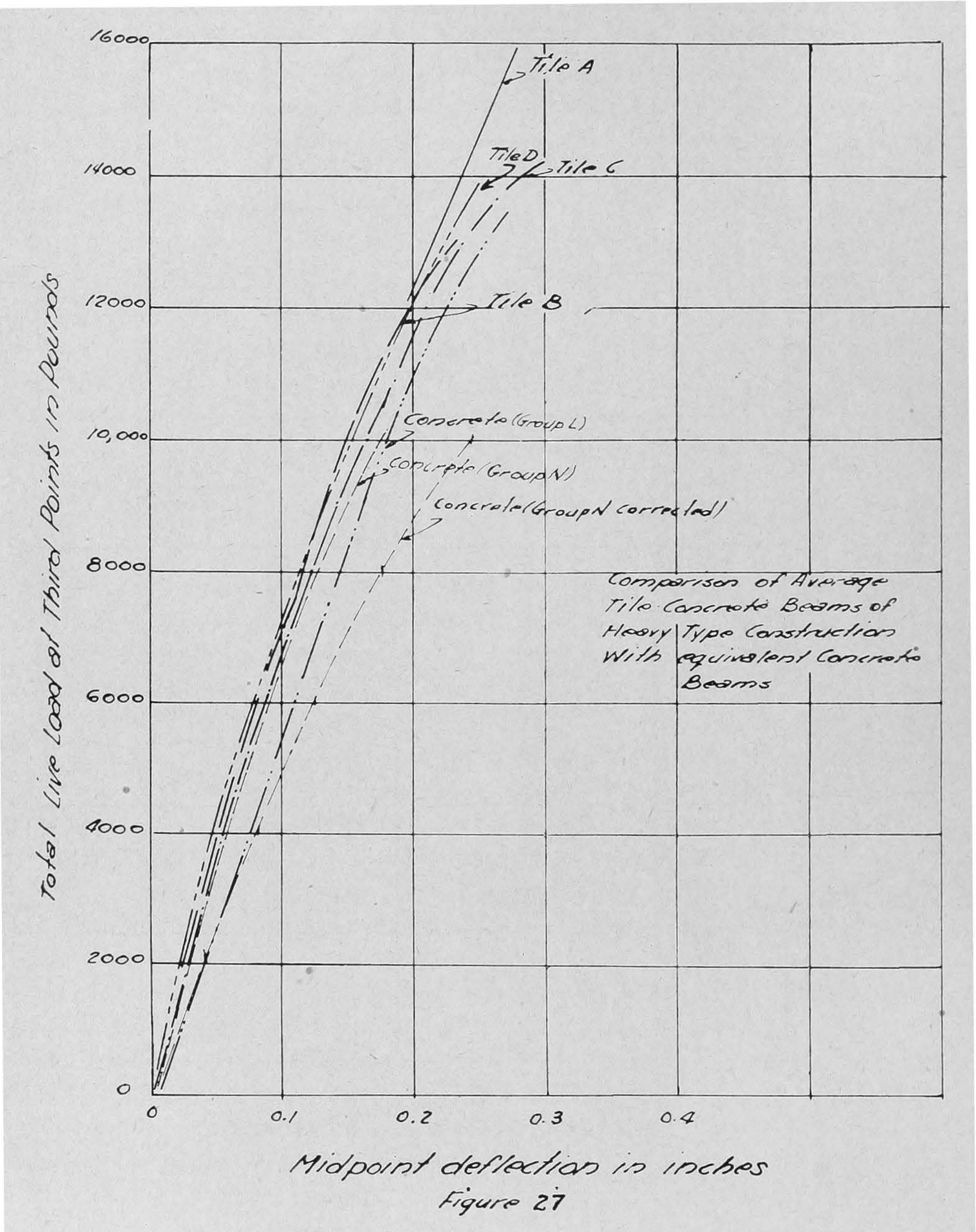

16000
14000
12000
10,000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
Total Live Load at Third Points in Pounds
Midpoint deflection in inches
Tile A
Tile D
Tile C
Tile B
Concrete (Group L)
Concrete (Group N)
Concrete (Group N corrected)
Comparison of Average Tile Concrete Beams of Heavy Type Construction With equivalent Concrete Beams

Figure 27

The slip along the plane of bond between the concrete and tile was measured by using the device shown in Figure 28. A hole was drilled through the concrete. The point of the instrument rested on the top of the beam tile and the metal plate was imbedded in plaster on the surface of the concrete. An Ames dial was fastened to the plate such that any differential movement between the tile and concrete would actuate the dial pin. There was no significant movement before failure of the beams except for the flush type beams of Tile C which failed on bond between the tile and the concrete.

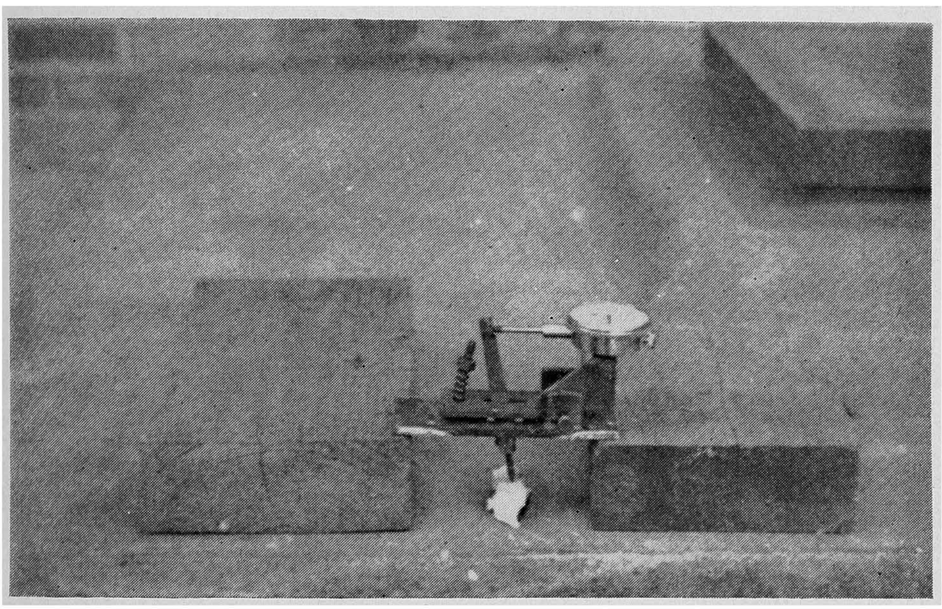


FIG. 28. Instrument used to measure slip between tile and concrete.

The results of the beam load tests were tabulated in Tables II and III. In order to compare the relative shear stresses at failure of the tile-concrete beams to the equivalent concrete beams, the ratio of the ultimate calculated shear stress to the cylinder compressive strength of the concrete was determined. This is common procedure for expressing the shear stress for concrete. The beams of Group R had the same loading diagram as the beams of Group H. In calculating the shear ratio obtained in the results of "An Investigation of 'U' Type Tile-Concrete Beams," by J. Neils Thompson and W. D. Ramey, it was found that the average shear ratio obtained there had an average value of 0.088. In that investigation the tile used was of the same type as tile A in this investigation. The average shear ratio of all beams except the steel bond failure of Tile A in Tables II and III was 0.1115 which is considerably higher than in the "U" type beam. However, if, instead of using only the concrete

TABLE NO. II

Comparison of Joistile-Concrete Flush Construction Beams with Concrete Beams

Beam Type	Beam Number	Design Load* (lbs./ft.)	Loads at Failure: Live: Total at third pts. (pounds)	Live: Equiv.† Unif. ld. (lbs./ft.)	Dead: Lbs. per ft.	Total: Lbs. per ft.	Calculated Shear Stress at Failure PSI	Comp. Strength of Conc. PSI	v/f'_c	Type of Failure	Revised v/f'_c
Joistile-Concrete Tile A	H–3	430	8,100	1,160	80	1,240	260	3,200	0.0812	Bond on Steel	0.0620
	H–6	430	9,900	1,410	80	1,490	312	2,870	0.1087	Diag. Tens.	0.0840
	H–9	430	11,040	1,580	80	1,660	347	3,030	0.1145	" "	0.0885
	H–13	430	10,950	1,570	80	1,650	345	3,290	0.1050	" "	0.0812
Joistile-Concrete Tile B	H–2	430	8,600	1,230	75	1,305	273	3,270	0.0835	" "	0.0646
	H–5	430	8,600	1,230	75	1,305	273	3,150	0.0866	" "	0.0670
	H–8	430	8,360	1,195	75	1,270	266	3,020	0.0881	" "	0.0681
Joistile-Concrete Tile C	H–4	430	7,050	1,010	80	1,090	228	3,520	0.0648	Bond on Tile	
	H–11	430	6,800	970	80	1,050	220	3,150	0.0700	Ditto	
	H–12	430	6,800	970	80	1,050	220	3,120	0.0706	Ditto	
Concrete	G–4	430	5,920	840	50	890	188	3,325	0.0566	Diag. Tens.	0.0566
	G–5	430	6,690	955	50	1,005	212	3,150	0.0673	" "	0.0673
	G–6	430	7,510	1,070	50	1,120	236	3,170	0.0744	" "	0.0744
Joistile-Concrete Tile D	H–14	430	11,710	1,670	75	1,745	366	3,320	0.1100	Diag. Tens.	0.0850
	H–15	430	10,790	1,540	75	1,615	338	3,160	0.1070	" "	0.0827
	H–16	430	10,180	1,450	75	1,525	320	3,390	0.0945	" "	0.0730
Joistile-Concrete Mortar Precast Tile A	R–1	430	5,060	720	80	800	166	3,000	0.0553	Bond on Tile‡	
	R–2	430	10,880	1,560	80	1,640	343	3,230	0.1062	Diag. Tens.	0.0821
	R–3	430	9,200	1,310	80	1,390	291	3,560	0.0817	" "	0.0632

*Designed Load based on an allowable shear stress of 90 lbs. per square inch.
†Calculated equivalent uniform live load for shear.
‡Failed at end of beam due to not having enough of beam over support.

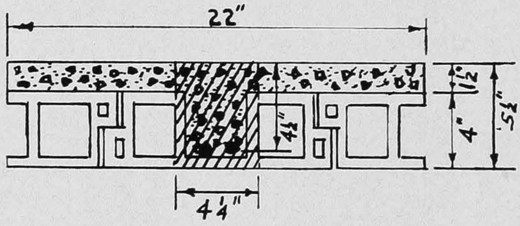
TABLE No. III

Comparison of Joistile-Concrete Heavy Construction Beams with Concrete Beams

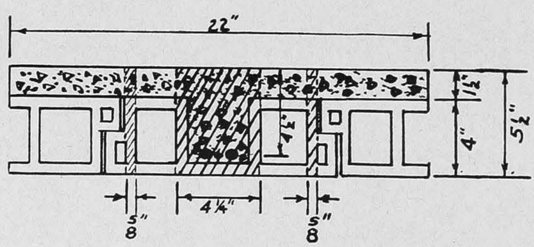
Beam		Design Load* (lbs./ft.)	Loads at Failure				Calculated Shear Stress at Failure PSI	Comp. Strength of Conc. PSI	v/f'_c	Type of Failure	Revised v/f'_c
			Live		Dead	Total					
Type	Number		Total at third pts. (pounds)	Equiv.† Unif. ld. (lbs./ft.)	Lbs. per ft.	Lbs. per ft.					
Tile A Joistile-Concrete Heavy Const.	K–2	597	16,250	2,320	95	2,415	364	3,140	0.1158	Diag. Tens.	0.0895
	K–5	597	14,480	2,050	95	2,145	308	2,830	0.1088	" "	0.0840
	K–8	597	16,920	2,420	95	2,515	380	3,260	0.1163	" "	0.0900
Tile B Joistile-Concrete Heavy Const.	K–1	597	13,180	1,880	90	1,970	296	3,340	0.0887	Diag. Tens.	0.0686
	K–4	597	11,650	1,640	90	1,730	260	3,350	0.0776	" "	0.0600
	K–7	597	14,160	2,020	90	2,110	318	3,500	0.0907	" "	0.0701
Tile C Joistile-Concrete Heavy Const.	K–3	597	12,880	1,840	95	1,935	292	3,050	0.0958	Diag. Tens.	0.0740
	K–6	597	15,910	2,270	95	2,365	356	3,020	0.1180	" "	0.0912
	K–9	597	15,390	2,200	95	2,295	346	2,970	0.1164	" "	0.0900
Concrete Equiv. to Heavy Const.	L–1	597	11,740	1,680	70	1,750	265	3,150	0.0841	Diag. Tens.	0.0647
	L–2	597	12,890	1,840	70	1,910	288	3,280	0.0879	" "	0.0675
	L–3	597	11,810	1,680	70	1,750	265	3,220	0.0825	" "	0.0634
‡Concrete Equiv. to Heavy Const.	N–1	597	10,270	1,470	60	1,530	206	3,000	0.0687	Diag. Tens.	0.0687
	N–2	597	10,360	1,480	60	1,540	207	2,990	0.0692	" "	0.0692
	N–3	597	9,260	1,320	60	1,380	186	2,540	0.0732	" "	0.0732
Joistile-Concrete Heavy Const. Tile D	K–10	597	13,190	1,880	90	1,970	297	3,490	0.0851	Diag. Tens.	0.0656
	K–11	597	14,720	2,100	90	2,190	330	3,340	0.0988	" "	0.0764
	K–11	597	15,640	2,230	90	2,320	350	3,320	0.1054	" "	0.0815

*Designed Load based on an allowable shear stress of 80 lbs. per square inch.
†Calculated equivalent uniform live load for shear.
‡Through an error in placing the steel the depth of this group of beams was 7 in. instead of the intended 6¼ in.

stem plus the two tile shells in contact with the stem, the outside shells of the beam tile were also used as part of the section in resisting diagonal tension stresses, the values of the revised shear ratios were obtained as shown in Tables II and III. For Tile A the average of these shear ratios is 0.0864 which compares favorably with the value obtained in the "U" type tile. This indicates that instead of having used the sections as shown in parts (a) of Figures 29 and 30 for calculation of shear and diagonal tension stresses, it would not have been improper to have used the sections as shown in parts (b) of Figures 29 and 30. In other words the



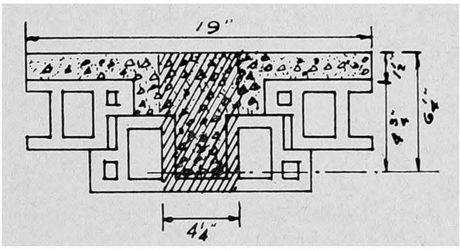
(a) Cross section of joistile-concrete flush beam.
Cross hatching indicates the section to use for calculation of shear stresses by the specifications



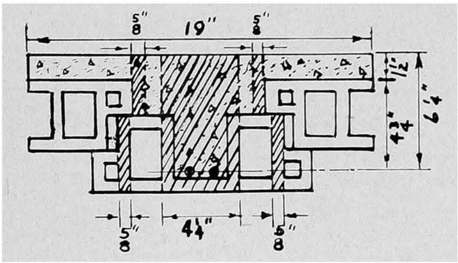
(b) Cross section of joistile-concrete flush beam
Cross hatching indicates the section used in the calculation of the revised shear stresses.

Figure 29

equivalent width of concrete was nearer twice the thickness of the webs in contact with the stem. The cause for this difference between the two types of tile beams could very well have been the fact that in the "U" type beam the maximum diagonal tension stresses are reached at a point where there was only the inner shells to resist those stresses; whereas, in the joistile type of beam the bond across the top of the tile allowed all the beam tile to act as a unit in resisting the stresses.



(a) Cross section of joistile-concrete heavy section
Cross hatching indicates the section to use in the calculation of shear stresses by the specifications



(b) Cross section of joistile-concrete heavy section
Cross-hatching indicates the section used in the calculation of the revised shear stresses

Figure 30

From the revised shear-compressive strength ratios it could be seen that there was no significant difference in the diagonal tensile strength between the flush construction and the heavy construction. Thus, the same conclusions would apply to both types of construction.

Figure 31 is a plot of the revised shear compressive strength of the concrete ratios versus the compressive strength of the tile used in the beam tests. This graph indicates that the diagonal tensile strength varies with the compressive strength of the tile. This relationship between compressive strength and diagonal tensile strength has no regular pattern probably because of the non-uniformity and wide variation of the strengths of both the beams and the tile.

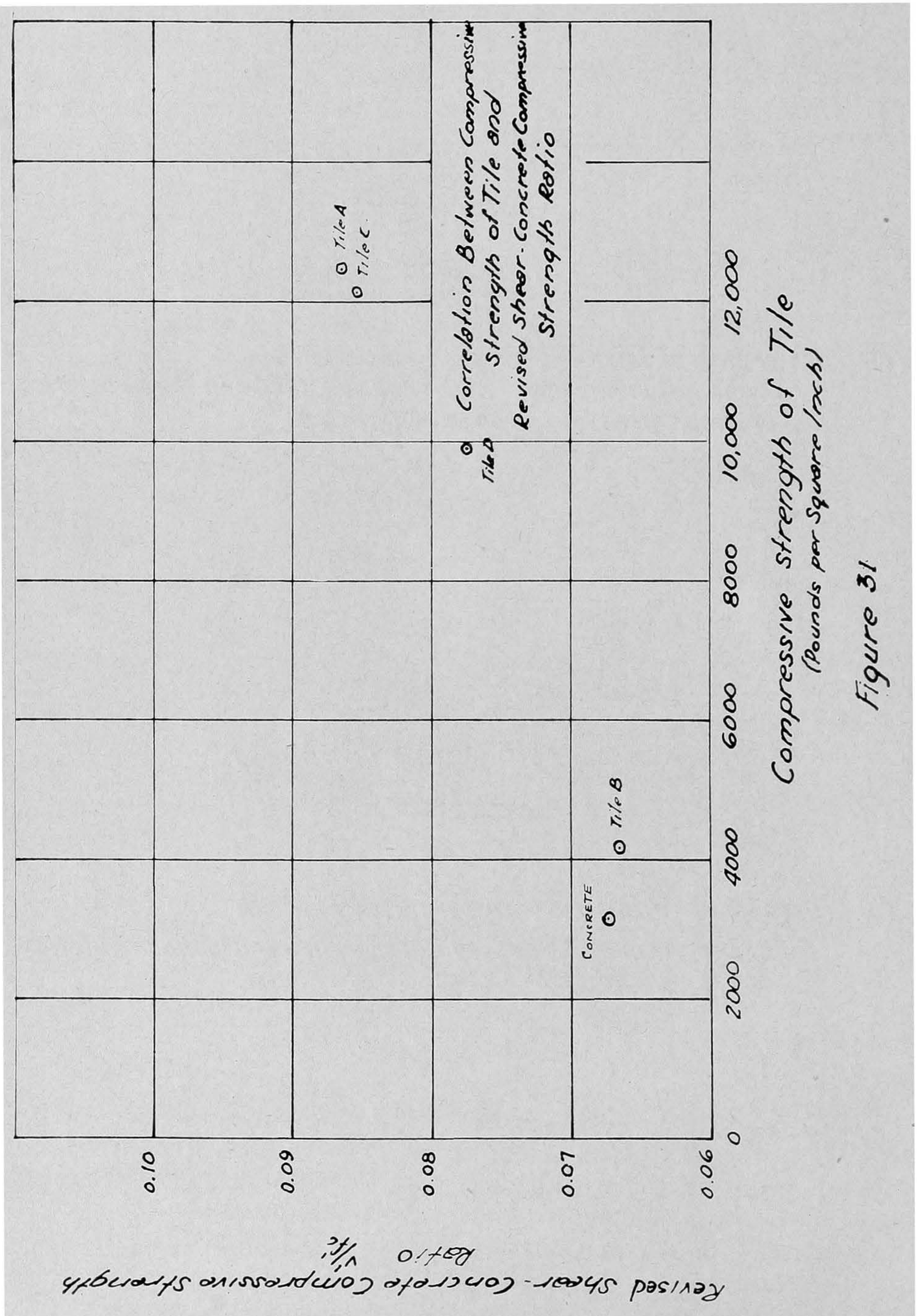


Figure 31

Proposed General Specification for Precast Tile Floor Systems

1. MATERIALS

a. *Structural tile units.* All structural clay tile floor units used in constructing the tile beams, joists, complete floor sections, and fillers or span tile shall conform to the designated design and the requirements of Grade M of Federal Specification SS-T-321, or Grade FT-1 of A.S.T.M. Specifications C57 as to strength, absorption, and workmanship with the additional requirement that the overall thickness of exterior shells shall be not less than the thickness used in the floor design.

Where kerfed units are required, they shall be so manufactured that the proper portion of the shell can be removed at the job without damage to the rest of the unit.

The tile shall be scored, combed or roughened on all exterior surfaces unless plaster is not desired directly on the lower surface, in which case such exposed face may be smooth. The interior surfaces of the units which will be adjacent to the concrete or grout shall be scored or roughened in manufacture to provide additional bond between the concrete and tile.

b. *Mortar.* (1) Mortar used in the assembly of joists or floor sections, when tested in the form of 2-inch cubes at 28 days, shall develop the ultimate compressive strength as indicated on the safe load tables for the particular floor system. In no case shall the requirements be less than that of a cement mortar containing 1 part portland cement, ¼ part hydrated lime and 3 parts of clean sand by volume proportion. Where the properties of ground clay mortar-mix are well established, equal proportions by volume may be substituted for the hydrated lime or lime putty designated.

(2) Mortar for setting the assembled sections at bearing supports and for the individual span or filler tile when required shall be as specified in 1-b-(1) above.

(3) Grout shall consist of mortar conforming to the requirements of Section 1-b-(1) to which sufficient water has been added to produce the required consistency.

c. *Concrete.* Where channels in the tile units are of sufficient width to permit the use of concrete, it shall conform to the ultimate compressive strength used in the design. In no case, however, shall the compressive strength at 28 days be less than 2,500 psi. (A satisfactory proportion mixture for 2,500 pound concrete consists of 1 part of portland cement, 2 parts of clean sharp sand, and 4 parts of washed gravel or crushed stone; with not more than 6½ gallons of water per sack of cement. High-early-strength cement may be used to speed construction.)

d. *Sand.* Sand for mortar or grout shall conform to A.S.T.M. Specifications for Aggregate for Masonry Mortar, C144.

Sand for concrete in wide channels and topping shall conform to the requirements for fine aggregate of A.S.T.M. Specifications C33.

e. *Stone and gravel.* Coarse aggregate used in concrete for wide channels or ribs and for topping shall conform to the requirements for coarse aggregate of A.S.T.M. Specifications C33 with the additional requirement that 100 per cent must pass a ½-inch sieve.

f. *Steel reinforcing.* The reinforcing steel used in precast joists, beams or floor sections shall be round or square of standard size as noted on structural drawings, and shall be of new billet (or rail) steel, meeting requirements of A.S.T.M. Specifications A15 for billet steel or A16 for rail steel.

2. CONSTRUCTION

a. *Assembly of beams and floor sections.* A firm and level surface shall be provided on which to precast the tile sections. Sections may be assembled on 2-inch casting planks of the proper widths which permit stacking of beams to conserve space while curing and facilitates handling. All precast beams designed to be installed without shoring shall be formed with a center camber of approximately ⅛ inch for spans up to 8 feet and increased in ⅛-inch increments for each additional 2-foot interval in span length.

The tile units shall be wetted thoroughly before using, and laid end to end against a straight edge until the desired length is attained.

NOTE: Where ends of units are ground true and level to insure complete end contact or where the tile are not figured as taking compression, the mortar between units may be omitted.

Before placing the reinforcing steel, mortar or grout shall be spread in the channel to a depth of ½ to 1 inch, after which the bars shall be placed and the balance of the mortar or grout slushed in. Sections containing deep channels shall be filled to a depth of not less than 2 inches or not more than 1 inch from the top of tile channel. The top surfaces in all cases shall be roughened with a wire or stiff fiber brush or by other means.

NOTE: Floor sections in which the reinforcing is placed through interior continuous holes do not require grouting provided the rod ends are threaded and supplied with large washers and nuts and thoroughly tightened to induce a prestressed condition.

b. *Curing of beams and floor section.* If portland cement is used, the beams must be cured at a temperature not less than 50° F. for a period of at least 48 hours and under moist conditions for four days and at least three additional days before being transported or placed in the structure.

(If beams or slabs must be inverted to place additional reinforcing steel, a period of at least 24 hours shall elapse before turning. High-early-strength cement is recommended for beams or slabs of this type.)

With high-early-strength cement, the beams or slabs shall be cured under moist conditions at a minimum temperature of 50° F. for at least three days before moving. Under any conditions, the precast sections shall be permitted to cure sufficiently before erection so that they can be handled without damage.

3. ERECTION

Precast beams, joists or floor sections may be handled and placed on the building by manpower, hand-hoists or such mechanical means as are available. They shall be properly spaced and placed in position with not less than 3 inches of bearing and shall be fully bedded in a mortar conforming to the requirements of Section 1-b-(1).

A single row of center-line shoring may be required for spans over 10 feet or as recommended by the manufacturer, and two rows of shoring at approximately the third-points shall be required on long spans.

Shoring shall be so adjusted that it will produce a camber of approximately 3/8 inch in 20 feet, and shall be left in place until the concrete topping has attained the required strength.

Where "filler" or "span" tile are required, they shall be placed on the shoulders of the supporting joists or beams as shown on the plans or details with a bearing of approximately 3/4 inch on each side.

For slabs designed on a continuous basis the spacing of abutting precast tile beams over bearings shall be such as to provide proper flow of concrete topping between ends of beams to assure proper continuity.

4. CONCRETE TOPPING

The tile and concrete surfaces shall be thoroughly cleaned and wetted and shall be allowed to surface dry before placing topping.

A concrete or grout mixture shall be used as recommended to develop at least the required ultimate compressive strength. Where a finished concrete surface is desired, the topping shall be floated to a true and level surface, unless otherwise specified.

If standard portland cement is used, the concrete topping shall be maintained at a temperature of at least 50° F. and not more than 100° F. for not less than three days after placing, and kept moist during a curing period of seven days.

If high-early-strength cement is used in the topping, the moist curing period may be reduced to not less than four days. In any event, shoring shall not be removed until the concrete has attained the required strength.

5. SUPPLEMENTARY SPECIFICATIONS

These specifications may be supplemented by manufacturers' requirements for various systems.

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